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Volume XLII, Number 1, Spring 2016

A Critical Meta-Analysis of Mobile Learning Research in Higher Education

By Hasan Al Zahrani and Kumar Laxman

ABSTRACT

This paper is a critical meta-analysis of mobile learning research based on qualitative descriptions of meta-analyses of m-learning research studies published between 2009 and 2013. The study covered in this paper looks at the conceptual frameworks and theories underpinning mobile learning research studies, the global experiences of using mobile digital devices for learning, and the factors enhancing or hindering the acceptance and use of mobile digital devices for learning in higher education. The study concludes that without reference to theoretical and pedagogical issues, including the design of m-learning, studies of m-learning will not necessarily further our understanding of how m-learning can contribute to successful learning outcomes globally.

Keywords: Mobile learning, meta-analysis, mobile devices in learning

CONTEXT OF STUDY

Mobile devices are "popular everyday tools and services that are also potential or de facto resources for education" (Kukulska-Hulme, 2012, p. 247). The increased availability of personal mobile devices is taking education and learning to a new level. It has been predicted that mobile devices will be the primary connection tool to the internet for most people in the world in 2020 (Anderson & Rainie, 2008). Mobile learning (m-learning) can be defined as examining how mobile technology can be used for educational purposes such as "the process of using a mobile device to access and study learning materials [and] to communicate with fellow students, instructors, or institution" (Ally, 2009). Mobility, informality, and personal ownership are all characteristics which make learning with mobile devices different from other forms of e-learning (Naismith, Lonsdale, Vavoula, & Sharples, 2004). Mobile devices allow e-learning to be delivered virtually anywhere at any time (Rouse, 2005). Mobile learning has been identified as a new stage of distance and e-learning (Georgiev, Georgieva, & Smrikarov, 2004). However, m-learning is more than using mobile technologies to access information and a potential solution to global demands for more access to education, m-learning represents a challenge to conventional education practices. Some of these challenges are explored in this critical metaanalysis of mobile learning research on the acceptance, readiness, and use of mobile digital devices for learning in higher education.

According to the United Nations Educational Scientific and Cultural Organization (UNESCO) there are currently over six billion mobile phone subscriptions worldwide, and for every one person who accesses the internet from a computer s/he does so from a mobile device. The emergence of the digital native generation, that is children who grow up using and relating to modern ICTs, provides a strong motive for research of learning with mobile devices in order to understand and achieve the potential educational benefits of m-learning. Although the focus of this paper is m-learning in higher education contexts, m-learning also has implications for employers and industries as an educational resource and training in other than educational contexts (Mungania 2003).

This study attempted to discover what benefit m-learning brings to education and to identify what questions remain unanswered by research in the field of m-learning. This study also examines current findings concerning social attitudes towards m-learning (acceptance), individual and institutional preparedness for pedagogical uses of mobile devices (readiness), and the impact of mobile learning on students' educational success (outcome). This review is guided by the following questions:

- What are the conceptual frameworks and theories underpinning mobile learning research studies?
- What have been the global experiences of using mobile digital devices for learning in the context of higher education?
- What factors are indicated by research as enhancing or hindering the acceptance and use of mobile digital devices for learning?

Rationale for a Critical Meta-Analysis

Gilliam and Zigler (2001) used the term 'critical meta-analysis' to describe their review of available impact evaluations from 13 state-funded preschools in the United States from 1977 to 1998. The concept of meta-analysis originates in the fields of psychiatry and medicine where it is "a standardized approach for examining the existing literature on a specific, possibly controversial, issue to determine whether a conclusion can be reached regarding the effect of a treatment or exposure" (Russo, 2007, p. 637). In the field of education "instead of students or participants being the unit of analysis, the primary studies themselves become the unit of analysis" (Denson & Seltzer, 2011, p. 216). The term critical is used in many different educational contexts. Critical thinking has been defined as:

> [A] way of deciding whether a claim is true, partially true, or false. Critical thinking is a process that leads to skills that can be learned, mastered and used. Critical thinking is a tool by which one can come about reasoned conclusions based on a reasoned process. This process incorporates passion and creativity, but guides it with discipline, practicality and common sense. [http://en.wikipedia.org/wiki/Critical_thinking].

In the context of this study, the term critical is used to identify trends in recent m-learning research and generate recommendations for future researchers in the field of m-learning.

The majority of meta-analyses used statistical techniques to combine the findings from independent studies into a single finding, in order to provide greater validity and reliability for those findings by producing an 'effect size' of the activity studied. Variation between studies "provides an opportunity to ask additional questions, and to investigate more closely the reasons for the observed differences in effect size across studies" (Denson & Seltzer, 2011, p. 216). However, because a statistical review does not always provide the degree of insight provided by interpretive approaches, some researchers argue for more qualitative descriptions. Qualitative descriptive studies have as their goal "a comprehensive summary of events in the everyday terms of those events" (Sandelowski, 2004, p. 334). This is the approach taken by Coursaris and Kim (2011) in their meta-analysis of empirical mobile usability studies. This study combines the basic meta-analysis procedure of systematic review with qualitative descriptions such as that taken by Coursaris and Kim (2011). This study also incorporates elements of the constant comparative method which compares recently collected data with data that was collected in earlier studies. This helps to establish the trustworthiness of a study (Lincoln & Guba, 1985). Lincoln and Guba (1985) argue that the trustworthiness of any research study is important to evaluating its worth. They identify four standards by which trustworthiness may be established:

- Credibility which establishes confidence in the 'truth' of the findings.
- Transferability which shows that the findings have applicability in other contexts.
- Dependability which shows that the findings are consistent and could be repeated by other researchers.
- Confirmability which indicates the extent to which the findings are shaped by the respondents and not researcher bias, motivation, or interest.

These four standards are used to guide this research. This study also aims to follow the frequently stated principle that the goal of a review is to "summarize the accumulated state of knowledge concerning the relation(s) of interest and to highlight important issues that research has left unresolved" (Creswell, 1994, p. 22).

SEARCH PROCESS

A combination of keyword and snowball searching was conducted to identify relevant literature and studies. Five different databases: ERIC, Google Scholar, ProQuest, A+Education and PsycINFO were searched for articles in peer reviewed journals using the keywords: 'mobile learning' and 'higher education.' In addition to peer reviewed journals a search of conference proceedings, papers and reports was conducted using the same keywords. The bibliographies of relevant articles and reports were also used to identify relevant material. Additional search terms: impact, acceptance, readiness, outcome, and achievement, were added to the original keywords to refine the search and filter the results. Theory and model were added as supplemental search terms part way through the search process. The search was limited to material published in English after 2005.

Inclusion and Exclusion Criteria

In addition to excluding studies published before 2005* and articles that were not based on original research, studies which could be identified primarily as product evaluations were excluded. Studies that examined m-learning in other than higher educational contexts, or only in K-12 educational settings were also excluded. An exception to this was made when the study included m-learning in higher educational settings. For example, although the meta-analysis of m-learning research trends by Wu, Wu, Chen, Kao, Lin & Huang (2012) includes studies of mobile devices used in K-12 and formal and informal education settings; the majority (95) of studies were concerned with formal education in higher education institutions. This criterion was also applied to the meta-analysis study of the use of audio podcasts by Hew (2009). Initially Hew's (2009) study was considered to be excluded because of the finding that the majority of the study participants used home based desktop computers rather than mobile devices to listen to audio podcasts. However, because of the current trend of replacement of static desktop computers with laptops and other mobile devices and the focus of the study being on the use of podcasts as an educational aid, Hew's study was considered relevant to be included. Mbarek and El Gharbi's (2013) meta-analysis is included because it covers the period from establishment of e-learning as an educational tool in higher education to the introduction of m-learning. Of the eight meta-analysis studies identified in the search process (see Table 1) and covered in this paper, three focused on research trends in m-learning studies. Another also looked at the research methodologies used. The remaining studies focused on some aspect of the acceptance, readiness or outcome of m-learning (see Table 2).

Close and repeated readings of the identified

TABLE 1: Meta-Analyses of m-Learning

Author(s)/Year	Title
Cheung & Hew[1] (2009)	A review of research methodologies used in studies on mobile handheld devices in K-12 and higher education settings
Hew (2009)	Use of audio podcast in K-12 and higher education: a review ofresearch topics and methodologies
Coursaris & Kim (2011)	A meta analytical review of empirical mobile usability studies
Hwang & Tsai (2011)	Research trends in mobile and ubiquitous learning: a review of publications in selected journals from 2001 to 2010
Pollara & Broussard (2011)	Student perceptions of mobile learning: a review of current research
Hung & Zhang (2012)	Examining mobile learning trends 2003–2008: a categorical meta-trend analysis using text mining techniques
Wu, Wu, Chen, Kao, Lin & Huang (2012)	Review of trends from mobile learning studies: a meta-analysis
Mbarek & El-Gharbi (2013)	A meta-analysis of e-learning effectiveness antecedents

Note.[1] In addition to being the co-author of the meta-analysis on the research methodologies, Hew is the author of the review of research topics and methodologies in studies of the use of audio podcast in K-12 and higher education (Hew, 2009).

*It should be noted that although all of the meta-analysis of m-learning are published after 2009 they include studies carried out before 2005.

studies were conducted to produce the qualitative descriptions of these meta-analyses as presented in the following sections.

Coding Procedure

The next stage of the research process was the coding of the selected studies. Once a study had met the inclusion criteria, it was assigned a unique code based on the author initial and dates of publication, then a brief description of the study and the study findings were entered into a table. The participant numbers, gender and underlying theory or models were identified when supplied by the original researchers. Additional alphabetical coding was then conducted using a letter or letters to identify the main subject of the study: student (S), teacher (T) or institution (I); the focus of the study, based on the previously identified search terms: acceptance (A), readiness (R) and outcome (O); the type of research: survey (SU), experimental (EX) or action research (AR); and, the research methods: quantitative (QN), qualitative (QL) and mixed method (MX). The initial coding took place before it was decided to focus on meta-analysis of m-learning studies and was applied to the meta-analyses. The coded data was then transferred to an Excel spreadsheet and Excel was used to filter and sort the studies according to the assigned codes.

DATA ANALYSIS METHOD

A combination of manual counting and computer assisted tabulation using Excel filters was used to analyse the data. Because the emphasis of this study is on qualitative description rather than statistical analysis, numerical counts and not percentage figures are used in the meta-analysis of m-learning reviews. Both percentage figures and numerical counts are used in the original meta-analysis m-learning studies conducted between 2005 and 2013.

Limitations of this Study

It is recognised that this study is necessarily limited in scope and there are aspects of m-learning that are not covered in depth. Further, although a comprehensive search of databases was conducted, because of the rapid spread of m-learning and the growing ongoing nature of research it is not possible to say that this study includes all relevant studies. In addition, it should be recognized that this review is based only on published reports that may present an incomplete picture of the actual research done and this could be subject to misinterpretation by the readers.

Overview of Meta-Analyses Studied

As noted earlier, four of the meta-analyses identified in the search process focused on research trends or research methodologies while the remaining meta-analyses focus on some aspects of the acceptance, readiness, or outcomes of m-learning (see Table 2). Most of the meta-analyses examined used some form of aggregation to establish a degree of statistical credibility for their findings. The exception is the meta-analysis conducted by Coursair and Kim (2011), which includes quantitative information from the studies examined but places more importance on the interpretation of those findings.

TABLE 2: Focus of meta-analysis studies

Focus of the Study	Count	Author(s)/Year
Research Trends	3	Hwang & Tsai (2011); Hung & Zhang (2012); Wu, Wu, Chen, Kao, Lin & Huang, (2012)
Research methodologies	1	Cheung & Hew (2009)
Acceptance (perception)	1	Pollara & Broussard (2011)
Readiness (usability)	2	Coursaris & Kim (2011); Hew, (2009)
Outcome	1	Mbarek & El-Gharbi (2013)

Research Trends and Methodologies

As noted in Table 2, three of the meta-analyses (Hwang & Tsai, 2011; Hung & Zhang, 2012; Wu, Wu, Chen, Kao, Lin & Huang, 2012) examine research trends in m-learning. These are considered by date of publication. It should be noted that the studies of Hwang and Tsai (2011) and Hung and Zhang (2012) were conducted concurrently and used the same database (SSCI) . Although there is a small difference in the time periods covered, there are many similarities in their findings. The fourth meta-analysis considered in this section (Cheung & Hew, 2009), which reviews the research methodologies used in studies of mobile handheld devices in K-12 and higher education settings also considers many of the same studies.

Research Trends in Mobile and Ubiquitous Learning from 2001 to 2010 (Hwang & Tsai, 2011)

Hwang and Tsai (2011) used the Social Science Citation Index (SSCI) database to identify items concerning mobile and ubiquitous learning published from 2001 to 2010. Hwang and Tsai specified the research sample group, the number of articles published, the contributing countries, and the research learning domains. They found that the number of papers published in the second 5 years of their study period was nearly four times (122) that of the first 5 years (32). The majority of these studies were concerned with student users of mobile devices for learning. Though a greater number of studies in the second period dealt with the experiences of teachers and working adults, student users from higher education and elementary schools remained the major samples of mobile and ubiquitous learning research. Few of the studies in the earlier period identified any specific learning domain and were "mainly focused on the investigation of motivations, perceptions and attitudes of students toward mobile and ubiquitous learning" (p.67). This contrasts with studies in the second period (2006-2010) which are more specific about the learning domains in which m-learning is implemented. Science, Languages, Arts, and Social Science are the main learning domains for studies of m-learning with a relatively few studies being carried out in Mathematics. Hwang and Tsai (2011) recognized the need for more longitudinal studies, but consider the availability of the large number of existing studies to be "good references for educators and researchers" (p. 69).

An interesting finding of Hwang and Tsai (2011) is the broadening distribution of countries contributing to studies in mobile learning. The majority of studies conducted in the first five years of the research period originated from the United States and the United Kingdom, followed by contributions from Taiwan. However, in the following five-year period there were increased contributions from other countries and Taiwan became the dominant contributor. The dominance of Taiwan is not explained.

Mobile Learning Trends 2003–2008 (Hung & Zhang, 2012)

Hung and Zhang (2012) used text mining techniques to conduct their meta-analysis of mobile learning trends between 2003 and 2008. They used the Web of Science database which includes the Science Citation Index (SCI) and the Social Science Citation Index (SSCI) to identify relevant studies using 'mobile learning' and 'm-learning' as their primary search terms. A total of 115 usable articles were retrieved. Hung and Zhang acknowledged that their decision to limit their study to the SCI/SSCI database and reliance on abstracts to identify relevant articles has limitations regarding the selection of material and the information provided – nevertheless it still provides a good overview of m-learning research trends. Documents were grouped based on the similarity of abstracts using the following four categories:

- Strategies and frameworks (22)
- Acceptance and issues (18)
- Effectiveness, evaluation and personalized systems (50)
- M-learning case studies (25)

Each category is divided into related topics, also referred to as clusters, which are then used as the basis of their analysis -- these include trends in frequency of each topic over time, the predominance in each topic by country, and preferences for each topic by journal. The top three research clusters that were identified were: m-learning tool development, effectiveness of m-learning and content protection, transmission, and management. Hung and Zhang identify two major growth phases of m-learning publications: 2003-2005 and 2007-2008. Studies of the effectiveness of m-learning contributed to the growth in both phases. In the second phase, studies concerning the acceptance of m-learning, adaptive evaluation or intelligent tutoring systems on mobile devices, m-learning tool development and m-learning projects in engineering education, language learning, and music education all contributed to the growth of m-learning publications. Research into collaborative m-learning was the only topic to decrease in publication. There were no significant fluctuations in the quantity of publications for topics such as strategies or frameworks for m-learning, interactivity of m-learning, acceptance of m-learning, personalized m-learning systems, m-learning in K-12 and other environments and issues such as content protection, transmission, and management throughout the research period. Hung and Zhang (2012) identified the period from 2003 to 2007 as the 'innovators stage' of m-learning studies" with the 'early adopters stage' beginning after 2007.

Hung and Zhang (2012) also included analysis of contributions of m-learning studies by the different countries. They found that both the USA and Taiwan were dominant in publications on interactivity of m-learning. Researchers in the United States were also concerned with instructional aspects of m-learning including collaborative m-learning and m-learning in K-12 environments. Taiwan dominated in 5 out of the 12 clusters: strategies or frameworks for m-learning, acceptance of m-learning, adaptive evaluation or intelligent tutoring systems on mobile devices, personalized m-learning systems and m-learning tool development. The dominance of Taiwan as a publisher of m-learning research was explained by pointing to the Taiwan's government's "strong and aggressive e-learning initiatives" and "financial, managerial and legislative support to promote e-learning development." It was suggested that China's lack of clear m-learning focus, despite the large quantity base of m-learning research "might be attributed to the lack of a strong mobile technology infrastructure there" (p. 13). No countries were dominant in the topics of effectiveness of m-learning, m-learning applications in training or m-learning projects in engineering education, language learning, and music education, although Turkey was the highest publisher of research concerning m-learning projects in engineering education, language learning, and music education.

Trends from Mobile Learning Studies (Wu, Wu, Chen, Kao, Lin & Huang, 2012)

Wu et al. (2012) analysed 164 studies from 2003 to 2010. Although they used Hwang and Tsai's (2011) and Hung and Zhang's (2012) meta-analyses as the starting points for their study, they however suggested that the two previous literature reviews "failed to examine or categorize research trends from the standpoint of research purposes, methodologies, and outcomes." Further, the earlier studies "failed to examine or analyse the mobile devices from the standpoint of teaching- and learning-assistance, and their critical role in ubiquitous learning." These authors did not consider that "the development and usage patterns of technology are changing quickly, requiring an up-to-date analysis of trends in mobile device types and functionality, along with learner types and the use of mobile devices in various disciplines and courses" (p.817-818). To overcome these failings Wu et al. included the purposes of the m-learning studies, the methodologies used and outcomes of m-learning use in their meta-analysis. From this they identified seven major findings (see Table 3).

Wu et al. note that it is particularly significant that most studies of m-learning focused on effectiveness and identify this as a significant new finding.

TABLE 3: Trends in Mobile Learning Research (Wu, Wu, Chen, Kao, Lin & Huang, 2012)

1	The research purpose of most mobile learning studies focused on effectiveness, followed by mobile learning system design.
2	Surveys and experimental methods were the preferred research methods, regardless of whether the research purpose focused on evaluation or design.
3	Research outcomes in mobile learning studies were significantly positive.
4	Mobile phones and PDAs were the most commonly used devices for mobile learning, but these may be replaced in the future by new emerging technologies.
5	Mobile learning is most prevalent at higher education institutions, followed by elementary schools.
6	Mobile learning most frequently supports students in the professions and applied sciences, followed by the humanities and formal sciences
7	The most highly cited articles fell into the categories of mobile learning system design followed by effectiveness.

Wu et al. attribute the more frequent citing of studies concerning mobile learning system design (7) to their earlier dates of publication because they have been available to researchers for a longer period of time. The finding that most m-learning studies feature positive outcomes (3) is an important one when it is known that m-learning is increasingly being adopted. It is no surprise that m-learning learning most frequently supports students in the professions and applied sciences (6) although Wu et al. suggest that m-learning can be applied to any course or subject matter.

Research Methodologies used in Studies on Mobile Handheld Devices (Cheung & Hew, 2009)

Cheung and Hew (2009) used the 'snowball' method to search for journal articles concerning the use of mobile handheld devices in K-12 and higher education settings published before December 2008, After excluding 92 articles of a total of 136 from their study because they were opinion papers, conceptual articles or non-empirical descriptions, Cheung and Hew examined 44 articles to identify how mobile handheld devices such as PDAs, palmtops, and mobile phones are used by students and teachers. They also look at the types of research carried out, the data collection methods used and the research focus of the different studies.

Cheung and Hew (2009) categorized the research methods used to study mobile device use into eight types: descriptive research, true experiment, experiment (weak), quasi-experiment, ex-post facto, single-subject, design-based research, and mixed method. They found that overwhelmingly the most used method was descriptive research (65.9%), the next most common research method used was weak experimental method (11.4%) where a single group is measured both before and after device use and there is no comparison or control group. Ex-post facto studies (where mobile device use had occurred prior to the study), single-subject and design-based research were the least used (one study each). One third (31.4%) of all data collection methods used questionnaire, 22.5% used test or quiz items, 20.6% used content analysis, 18.6% used interview or focus group, and 6.9% used observation. Cheung and Hew (2009) suggested that questionnaires and test or quiz items are the most frequently used methods of data collection because they can collect data from a large sample and are relatively easy to use.
Cheung and Hew (2009) identified seven major categories of use for mobile devices in education: (a) multimedia access tool, (b) communication tool, (c) capture tool, (d) representational tool, (e) analytical tool, (f) assessment tool, and (g) task managing tool. They noted that the first five categories originated from a framework put forward by Churchill and Churchill (2007) from a case study of a teacher who explored "the educational affordances of PDA technology" over a period of six months (p.1439). The remaining two uses of mobile devices as assessment tools and task managing tools emerged inductively from the data.

The four main research topics found were usage profile (26.3%), the viability of mobile devices as an assessment tool (7%), learning outcomes after using mobile devices (17.5%), and user attitudes (49.1%). The studies indicated that mobile handheld devices are most commonly used by students and teachers as communication and multimedia access tools. Cheung and Hew (2009) attributed this to the convenience and portability of handheld devices. However, they suggest that the dominant use of mobile devices as multimedia access tools indicated that mobile devices function primarily as replacements for other means of multimedia access rather than functioning in uniquely transformative ways. Acceptance of mobile devices is linked closely to physical features such as portability and ease of use while resistance is linked to unfamiliarity with devices as well as physical limitations such as limited battery life, limited memory, small screen size and difficulties in making inputs using the stylus or phone keypads. Limited Internet browsing through server capabilities or formats on small screens were also considered barriers.
Cheung and Hew (2009) found that although the research regarding learner outcomes appears to suggest that students' learning is enhanced through the use of mobile handheld devices, they note that this finding should be viewed with caution because of the lack of rigorous research designs used in these studies. They also advise that before universities and schools invest in mobile devices "it may be more crucial to investigate the cost effectiveness of using a mobile handheld device" for learning (p.167). In the few studies concerning the use of mobile devices as an assessment tool, there was no significant difference in terms of test scores achieved by students using the PDA and paper and pencil based assessment methods.

Acceptance, Readiness and Outcomes of m-Learning

The second category of meta-analyses was that which covered studies concerned with the acceptance, readiness, and outcomes of m-learning (Coursaris & Kim, 2011; Hew, 2009; Pollara & Broussard, 2011; Mbarek & El Gharbi, 2013) . Although the specific focus of each study varied from the use of a specific m-learning application such as Hew's (2009) review of the use of audio podcast in educational contexts to more general studies of usability such as Coursaris and Kim's (2011) meta-analysis, they all dealt with aspects related to the acceptance, readiness and outcomes of m-learning.

The use of audio podcast in educational contexts (Hew, 2009)

Hew (2009) reviewed 30 studies concerning the use of audio podcast in K-12 and higher education settings. The majority of the studies reviewed were descriptive. Although K-12 education settings are included, most podcasts were used in higher education and traditional course settings. Using a constant comparative method, Hew identified three major research categories: how participants use podcasts including barriers to using podcasts; the cognitive and affective outcomes of podcast use; and, the institutional aspects of podcast use, specifically: the impact of podcast on learner attendance in class/lectures and the costs of producing podcast.

The study found that although podcasts may be played on a variety of mobile devices in the majority of studies "students both in the traditional and distance education settings tend to listen to the podcasts at home using desktop computers, rather than on the move" (p. 348). There was also a preference for shorter (5-10 minutes) podcasts that longer (over ten minutes). Students generally enjoy using podcasts -- however they did not always consider them to be relevant to their learning. The availability of podcasts did not appear to encourage students to skip classes. Barriers to using podcasts could be categorized as either student-encountered or instructor-encountered. The barriers to student use of podcasts were unfamiliarity with podcasts, technical problems in accessing and downloading podcasts, and students not seeing the relevance of podcasts for their learning. Instructor-encountered barriers also included unfamiliarity with podcasts and not seeing the relevance of podcasts for their subject areas. Another barrier was lack of time to prepare podcasts. The review found that the most common pedagogical use of podcasting was limited to instructors distributing podcast recordings of lectures or supplementary materials to enable students to review subject material at their own time and place.

To help mitigate the possible novelty effects of using audio podcasts, Hew suggested that future research needs to be carried out over a longer period of time, to examine the impact of using podcast on students' learning and affective domains.

Student Perceptions of Mobile Learning: Review of Current Research (Pollara & Broussard, 2011)

Pollara and Broussard (2011) reviewed 18 reports published between 2005 and 2010 of studies of learning with mobile devices in a variety of different contexts. They focused specifically on student perceptions of mobile learning, although they also considered the types of technology used, the learning tasks involved, the kinds of interactions technology was used to support, the outcomes measured, and the design and methodology of the study -- excluding studies that did not provide adequate information about research design or methodology. Their review was limited to experimental and non-experimental studies which examined mobile devices that were personally owned and used by students, such as PDAs, mobile phones, and mp3 players and were used for either formal or informal learning or as part of practical work experience or practicum. Although case studies were excluded as "too restrictive" (p. 1645) because they were case specific, no restriction was placed on sample size. Six (6) of the studies were experimental and twelve (12) were survey driven. Fourteen (14) involved the use of mobile phones or PDAs and two studies concerned mp3 players. No device is specified in the remaining two studies. The two studies involving mp3s specifically were concerned with podcasts for educational purposes. Pollara and Broussard (2011) noted that technological convergence means that many mobile devices may now be used for multiple purposes. Learning tasks varied between studies with some studies looking at more than one task. These tasks were identified as the following way: tasks facilitating the individual learning of content (5), group projects/discussion (6), assessment (6), and teacher-directed lecture through the use of the m-learning technology tool (2). The most commonly used types of interactions with mobile device were between student and content (14) followed by interactions between student and instructor (11) and interactions amongst students (8). All of the studies except for one reported overall positive results for student perceptions of m-learning. The remaining study reported mixed results with respect to student attitudes on m-learning.

In the positive reports Pollara and Broussard (2011) found that:

- Three (3) studies reported that m-learning generated a strong interest amongst the students
- Eight (8) studies reported a strong, positive reaction to integrating m-learning into the classroom
- Three (3) studies reported that learners found that learning with mobile devices was enjoyable
- Five (5) studies reported that students recognized the potential of m-learning
- In four (4) studies "participants found that using mobile devices was convenient and enabled learning to be flexible and portable because of the portability and perceived convenience associated with mobile applications and tools" (p.1646)
- Three (3) studies found that students reported competence and ease in using the devices and performing the learning tasks.

Student participants with previous experiences of mobile devices were more likely to encounter fewer problems with m-learning. Students already aware of m-learning in two (2) studies reported little or no change in their perceptions, either positively or negatively of m-learning. Expense is the only deterrent to m-learning identified in one study. Pollara and Broussard (2011) note that only four studies looked at both student attitudes to m-learning and student achievement gains from m-learning; thirteen (13) studies focused exclusively on student attitude to m-learning and one study was designed specifically to focus on student achievement gains. Pollara and Broussard (2011) also noted that researchers did not appear to be specifically interested in how a particular m-learning strategy can influence achievement because their concern was whether participants are amenable to the use of m-learning as an educational tool.

A review of mobile usability studies (Coursaris & Kim, 2011)

Coursaris and Kim's (2011) carried out a qualitative review of more than 100 studies of user perceptions of mobile learning devices and studies of using mobile devices for learning, published between 2000 and 2010. To analyze the finding of the studies they developed a framework of contextual usability for mobile computing based on key usability dimensions, contextual factors and consequences. Usability is defined as the degree "that people can employ a particular technology artifact with relative ease in order to achieve a particular goal within a specified context of use" (p. 118). Key usability dimensions include effectiveness, efficiency, satisfaction, errors, attitude, learnability, accessibility, operability, accuracy, acceptability, flexibility, memorability, ease of use, usefulness, utility, and playfulness. Four contextual factors affecting usability were identified as the following: user, technology, task/activity, and environment. Task characteristics were identified as open and closed tasks. Consequences refer to the result or end purpose of using the mobile device, for example, improving systems integration, increasing adoption, retention, loyalty, and trust. The study was carried out in two phases; as a result Coursaris and Kim were able to compare studies carried out before 2006 with studies conducted after this time. Coursaris and Kim (2011) found that overall:

- empirical mobile usability studies focused on investigating task characteristics (47%), followed by technology (46%), environment (14%), and user characteristics (14%). Distribution exceeds 100% as multiple areas may have been studied in a single study. This contrasts with the distribution of research emphasis in the earlier phase which showed research on task (56%), user (26%), technology (22%), and environmental characteristics (7%).

There is a lack of empirical research on the relevance of user characteristics and the impact of the environment on mobile usability. Coursaris and Kim (2011) pointed out that "because on-screen keyboards are now a standard of smartphone technology, it would be important to understand the optimal design of on-screen smartphone/mobile device keyboards according to target user groups and their characteristics" (p.122). Additional findings of the Coursaris and Kim (2011) meta-analysis are that:

- Open and unstructured tasks, interactivity and complexity are understudied.
- User characteristics: A narrow focus on studied user dimensions is prevalent
- Technology characteristics: Enabling technology beyond the interface is overlooked in mobile studies
- Environmental characteristics: Area with greatest potential for future mobile usability research

Coursaris and Kim (2011) found “efficiency, errors, ease of use, effectiveness, satisfaction, and learnability are most commonly measured in empirical mobile usability studies” (p. 128). After reviewing the frequency with which the different measures appeared in the reviewed literature, Coursaris and Kim (2011) identified three core constructs for the measurement of usability of m-learning. These are:

- Efficiency: Degree to which the product is enabling the tasks to be performed in a quick, effective, and economical manner, or is hindering performance.
- Effectiveness: Accuracy and completeness with which specified users achieved specified goals in a particular environment.
- Satisfaction: The degree to which a product is giving contentment or making the user satisfied. (p. 128)

Coursaris and Kim (2011) pointed out that these findings could easily be predicted and don’t introduce anything new to the field, which they suggest raises questions about the continued use of these measures for usability studies on the implementation of m-learning in the future.

Antecedent of e- learning effectiveness (Mbarek & El Gharbi, 2013) Mbarek and El Gharbi (2013) reviewed 60 research reports of studies concerning employees or students in learning programmes designed to prepare them to reproduce and generalize knowledge and skills for class or job tasks. Included is research that reported gain scores, learning achievement, and training performance between 1984 to 2009. This period covers the establishment of e-learning as an educational tool in workplaces and formal educational contexts and the introduction of m-learning. Mbarek and El Gharbi (2013) examined the variables identified by researchers as contributing to or limiting positive learning outcomes and learning transfer using the concept of nomological networks. Trochim, (2006) explained the nomological network as a means of linking the conceptual/theoretical realm with the observable one by identifying the concepts of interest in any study and the interrelations among and between them.

Mbarek and El Gharbi (2013) presented their findings: they first identifyied the focus of m-learning studies regarding factors contributing to the affectiveness of e-learning (see Table 4). These variables are divided into trainee characteristics: motivation to learn, self-efficacy, and anxiety. And, contextual characteristics: feedback (positive and negative), training method, learning delivery.

TABLE 4: *Focus of m-learning studies (from Mbarek & El Gharbi 2013)*

Factors contributing to e-learning effectiveness	Number of Studies
motivation to learn	22
self-efficacy	28
anxiety	6
learning delivery	21
training method	10
feedback	6
learning performance	4

Based on their meta-analysis Mbarek and El Gharbi concluded that motivation to learn has a moderate relationship with learning outcomes; self-efficacy has a small relationship with learning outcomes (see Table 5). Anxiety has a significant relationship with learning outcomes. Training method has an important relationship with learning outcomes. Learning outcomes are positively related to learning transfer. Learning delivery has a small relationship with learning outcomes. Feedback has a strong relationship with learning outcomes.

TABLE 5: Impact of variables on learning outcomes and learning transfer (from Mbarek & El Gharbi 2013)

Small	Medium	Large
self-efficacy	motivation	anxiety
learning delivery		training method
		feedback

Mbarek and El Gharbi (2013) recognized that some of studies in their review were based on small sample sizes. Further, their review focuses on the analysis of the variables that have been directly correlated to learning performance -- other possible moderators such as self-efficacy and learning outcomes are not examined. Mbarek and El Gharbi concluded that despite efforts to gain a greater understanding of the factors which lead to e-learning effectiveness, researchers have not reached a consensus on the interrelations among and between these factors or their impact on learning outcomes.

CONCEPTUAL FRAMEWORKS AND THEORIES

This study shows that a number of authors have made efforts to identify conceptual frameworks and theories specifically appropriate to the use of mobile devices for learning (for example, Sharples, 2000; Sharples et al., 2005; Berking et al., 2012). Although there is reference to these efforts in the meta-analyses and studies reviewed, there is little evidence that theory plays a significant role. The exception to this is the use of variations of TAM and other models related to predictions of technology acceptance. The design of m-learning is identified as an important aspect of m-learning in some of the studies – however, there is little examination of how design or lack of it affects learner outcomes. There is some evidence that the design of m-learning is becoming more important (Wu et al., 2012). Wu et al. (2012) suggested that the increase in the number of studies related to m-learning design is related to rapid development of potential m-learning technologies combined with the willingness of researchers to trial those new technologies in developing mobile learning systems. But in general there is a noticeable lack of emphasis on pedagogical issues. Cheung and Hew (2009) found that the majority of the studies "tended to place greater emphasis on the features of the mobile devices and procedures for using them, rather than on the theoretical rationale or justification for using them" (p.166). Hwang and Tsai (2011) noted that there is greater attention to learning domains made in the later period of their meta-analysis (2006-2010) but do not give any indication of the extent to which studies focus on the pedagogical role of m-learning or learning outcomes using mobile devices. Like Cheung and Hew (2009), Hwang and Tsai (2011) also recommend that future researchers consider this aspect of m-learning more deeply.

It should be noted that Wu et al. (2012) identified the evaluation of the effectiveness of m-learning to be emerging as a dominant area of research. This can be attributed to the increased use of mobile devices in education and concerns about the effectiveness of m-learning. A second interesting point concerns the preferred research methods used by m-learning researchers. Wu et al. found that regardless of whether the research purpose focused on evaluation or design, the preferred research method was usually surveys. Wu et al. do not provide any rationale for why this is so, nor do they examine potential weaknesses of surveys as a research method. Pedagogical preparedness by teachers and institutions appears to be only covered incidentally in m-learning research. While this may be attributed in part to a lack of research in the area, it may also be attributed to an underlying lack of attention to pedagogical concerns. This is a serious oversight. Mishra and Koehler (2009) pointed out that "if you're not going to change pedagogy, then technology uses make no significant difference." To be effective, m-learning must be supported by good pedagogic practices.

Global Experiences

Overwhelmingly the experience of using mobile digital devices for learning is presented as a positive experience regardless of the application or type of mobile device. Much of the research about m-learning concerns the impact of using mobile technology and the effect of using mobile devices on learners' motivation to learn. It has been suggested that it is the feelings of ownership associated with the use of mobile devices and the informality of many m-learning applications which help motivate students by engaging them in activities that they like and give them a sense of control over their learning (Pollara & Kee Broussard, 2011). The feelings of ownership and motivation to learn with mobile devices help promote good habits of learning and are the reason that m-learning is considered to contribute to developing life-long learning skills. This may also explain why acceptance studies dominate m-learning research. It should also be noted that although there is evidence of an increase in studies of teachers and working adults' experience of m-learning (Hwang & Tsai, 2011) students remain the major subject of mobile learning research studies. Neither gender nor age appear to be significant factors in the acceptance, readiness to use or experience of m-learning (Uzunboylu, Cavus, & Ercag, 2008; Wang, Wu, & Wang, 2009) although there is evidence that familiarity with technology is an important factor. In their review of research trends Hung and Zhang (2012) note that they could not find any longitudinal studies focused on m-learning and suggest this is due to the relatively short history of using m-learning. The lack of research concerning learning outcomes may also be attributed to the relatively short history of m-learning; however, it does not explain the lack of attention to institutional and teacher acceptance and readiness or how learning with mobile devices may be successfully integrated into pedagogic practice. Pollara and Broussard (2011) observed that researchers do not appear to be specifically interested in how a particular m-learning strategy can influence achievement and this reveals two important things about m-learning research to date. First, because the focus of researchers is on whether participants are agreeable to the use of m-learning as an educational tool, they fail to investigate how and in what ways m-learning can contribute to positive learning outcomes. However, acceptance of the possibility of learning through the use of mobile devices does not indicate individual and institutional readiness for m-learning or evaluate the impact of teaching and learning using mobile devices.

Hung and Zhang (2012) present a more detailed analysis of research trends in m-learning than Hwang and Tsai (2011). Through their text mining techniques and identification of topics, Hung and Zhang show how the concerns of researchers have changed from 2003 to 2008. They link this directly to developments in m-learning technology and suggest that this both “created new possibilities for research” (2012, p.10) and contributed to the frequency of m-learning articles in journals. The increased contribution from researchers from countries other than the United States and the United Kingdom (Hwang & Tsai, 2011; Hung & Zhang, 2012) undoubtedly reflects the growth of m-learning globally.

From this global research we can expect to learn more about the impact of m-learning in different cultures. As noted earlier the role of culture in education is frequently controversial, however it is impossible to avoid this factor when looking at educational issues globally. Cheung and Hew (2009) identified a relationship between culture and m-learning as an area for further study but do not themselves address culture in relation to m-learning. However, there is some evidence that culture influences attitudes toward m-learning. In their discussion of the factors influencing the adoption of e-learning at University of Bahrain, Al-Ammari and Hamad (2008) included culture as a significant factor. Based on the results of a study that asked participants from various cultural backgrounds to perform a number of e-learning tasks, Adeoye and Wentling (2007) found that suitable awareness of cultural diversities and the effects this has on the individual user is vital to the success of e-learning systems.

Relevant Factors

Abachi and Muhammad (2013) noted that although a growing number of academics accept that today’s mobile devices are tomorrow’s textbooks, there are still issues related to the use of a mobile device for learning that must be resolved before m-learning achieves its fullest potential. As discussed previously, the most frequently quoted factors affecting the successful implementation of m-learning in educational contexts are: technology, accessibility, affordability, acceptance, readiness and support. To this list, the understanding of m-learning can be added. This study suggests that the limited knowledge and understanding of m-learning by teachers represents significant barriers to the successful implementation of m-learning. Trifonova, Georgieva, and Ronchetti’s (2006) study revealed that there can be a lack of understanding of m-learning even when students are accustomed to using mobile devices. Hew’s (2009) review of the use of audio podcast in K-12 and higher education settings found that a lack of familiarity with podcasting technology limited how both teachers and students used podcasts.

The successful implementation of m-learning in educational contexts may be affected by teachers’ attitudes toward learning with mobile device -- the ways teachers create opportunities for learning with ICT are “highly dependent” on the “pedagogical orientation” that teachers adopt (Law, Pelgrum, & Plomp, 2008, p. 275). Research suggests that for m-learning to be used effectively both students and faculty must be ready and open to the potential benefits of a change in the teaching and learning environment.

Recommendations for Future Research

A recurring claim by researchers in any field is that more research is necessary. A review of the literature related to m-learning shows that there is already a large body of research about m-learning, but the majority of studies continue to focus on the attitudes and perceptions of the users rather than the impact of using mobile devices for learning or the problems of integrating m-learning with other pedagogic practices. The imbalance of the research focus of m-learning studies and the use of weak experimental methods and concentration on self-reported data identified by Cheung and Hew (2009) support the argument that there has not been enough research around learning outcomes related to m-learning or the implications of m-learning for assessment. To gain a true picture of the impact of m-learning in higher education more longitudinal observational studies should be conducted.
One of the difficulties experienced by Mbarek and El Gharbi (2013) in their meta-analysis of m-learning research was the wide variety of variables used by researchers to measure the effectiveness of learning outcomes. This suggests that more effort is required by researchers to be consistent in their approach to evaluations of m-learning. Although there are weaknesses to be found in the analysis of m-learning research trends of Hung and Zhang (2012) and Hwang and Tsai (2011), together they form a strong foundation for future analyses of research trends in m-learning particularly when combined with the insights of Wu et al. (2012). These studies offer many useful suggestions for future research. For example, note the suggestion from Hung and Zhang (2012) that future researchers “should pay more attention to interdisciplinary approaches to research and development of ML in order to synthesize knowledge from both disciplines” (p. 13).

There are clear indications that the use of mobile technologies will continue to increase globally, and it is the challenge for educators to ensure that m-learning will be part of their use. Although more empirical evidence of the benefit of m-learning to learning outcomes is needed (Laxman, 2012), research indicated that m-learning is beneficial particularly with respect to the development of lifelong learning habits and skills. To gain from the potential benefits of learning with mobile devices, schools and teachers need to be well informed about all aspects of m-learning -- not only on how to use the technology but what they need to do to support m-learning through pedagogical changes. For this reason more attention should be given to pedagogical preparedness of teachers and institutions for m-learning. It has been argued that in order to be effective, learning via mobile devices must follow good instructional design (Berking et al. 2012). This suggests that more research with an emphasis on m-learning instructional design should be conducted. Research shows that in general technology acceptance is not a problem, m-learning research needs to move beyond issues of acceptance of technology to how that technology may best be used.

CONCLUSION

As digital technology advances and the use of PDAs, such as the iPhone and the iPad make online learning more accessible, it is likely there will be more use of mobile technologies in education both in the United States and globally. However, as Basta (2009) warned us, “Excessive confidence in information and communication technologies in the learning discipline may lead to a situation similar to the dot-com [bubble] burst that happened in the late 2000” (p. 1). This study shows there is a significant absence of attention being paid to pedagogical details in conceptuaizing m-learning research. Although, as many studies indicate, m-learning is attractive to learners, the use of mobile technology does not guarantee that effective learning will occur. Without reference to theoretical and pedagogical issues, studies of m-learning will not necessarily further our understanding of how m-learning can contribute to successful learning outcomes globally. As Laxman (2012) pertinently pointed out: “Gratuitous use of technology for the sake of technology will not necessarily improve teaching and learning processes” (p. 48). M-learning can only bring about an improvement in learner outcomes when it is matched by the application of pedagogical practices that take into account the characteristics and opportunities presented by m-learning and recognize the demands of the differentiated educational and cultural contexts it will be used in.

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An Assessment of the Use of Social Media in the Industrial Distribution Business-to-Business Market Sector

By Rod L. Flanigan and Timothy R. Obermier

ABSTRACT

The way B2B companies use social media continues to evolve as technology improves and as demographics continue to change. The industrial distribution market sector is no different than many other markets in that the industry continues to search for ways to reach out to both existing and new customers. The industrial distribution industry has been slow to adopt new marketing tools, relying heavily on the tried and tested model of personal selling via personal relationship. As the Millennial generation continues to enter the workforce, their consumer buying expectations are different than that of the Baby Boomer generation, and they have a higher comfort level in using new technology to enhance efficiencies at work. This study evaluated the use of social media among the top industrial distributors in the United States, and it compared that information to the top industrial manufacturers in the United States. This information was then compared to similar data from Fortune 500 companies.

Keywords: industrial distribution, social media, industrial marketing

INTRODUCTION

Social media has revolutionized the way many industries and market segments share, communicate, modify, create, and discuss product content and services (Kietzmann, Hermkens, McCarthy, & Silvestre, 2011). Across the entire landscape of modern society, the proliferation of social media has completely changed the way government, large and small businesses, sports teams, nonprofits, and most organizations communicate with their stakeholders (Peltola & Makinen, 2014). For example, in January, 2016, President Obama had over 6.9 million Twitter followers; NASA had nearly 15 million Twitter followers; and LeBron James, an NBA basketball player, had nearly 28 million Twitter followers.

Yet, despite the proliferation of social media in today's market and the success many companies and industries have experienced with the use of social media in both a business-to-consumer (B2C) and business-to-business (B2B) setting, some very successful companies still do not use social media, and others do not use it either efficiently or effectively (Aichner & Jacob, 2015). Countless sales books, news articles, and other research publications promote the idea that interpersonal relationships, including face-to-face selling techniques are the most effective sales strategies in a B2B environment that involves complex negotiations, long sales cycles, and may involve many people in the process (Long, Tellefsen & Lichtenthal, 2007; Singha & Koshyb, 2011). Although the importance of interpersonal relationships is still an integral component of selling highly technical products and services in industrial markets, the limited face-to-face time sales people have with customers adds to the importance of social media in staying connected with customers (Jarvinen, Tollinen, Karjaluoto, & Jayawardhena, (2012).

Fortune 500 companies have begun to understand the value of a social media presence. In 2011, nearly 83% of Fortune 500 companies were engaged in some form of social media to connect with either their customers or consumers (Naylor, Lamberton, & West, 2012). To further illustrate the importance of, and necessity for social media in B2B trade, the Millennial generation is entering the workforce at an unprecedented rate, and this technology-savvy generation is changing how business is conducted. In the B2C market, an effective social media campaign can generate positive word-of-mouth advertising, as well as create viral effects in the market (Hanna, Rohm, & Crittenden, 2011; Weinberg, & Pehlivan, 2011). The B2C market has found numerous ways to capitalize on the use of social media. Some of these include developing brands, developing new markets and customers, conducting market research, recruiting new personnel, exchanging ideas, and ultimately driving revenue growth. The use and exploitation of social media in the B2C market is staggering. In 2014 it was estimated that nearly 81% of small- to medium-sized B2C enterprises (SMEs) used social media to drive business growth, and that over 91% plan to use it in the future (Eddy, 2014).

Even though this sort of market penetration and advertising may work effectively in a consumer market, the industrial B2B market sector is completely different; historically, it has used different marketing strategies. For example, industrial B2B companies have fewer followers on their social media sites; thus, they have less opportunity to gain word-of-mouth advertising from social media that a consumer product may get (Jarvinen et al., 2012). This idea has led many companies in the industrial market to question how social media can be used for their benefit. This problem, combined with the cost of building and maintaining social media sites has meant that many B2B companies have been slow to adopt the technology.

The B2C market has clearly capitalized on the many benefits of using social media in a marketing campaign. Research has been slower to help define how B2B companies, in specialized markets, can best use this media. Though many companies are experimenting with and learning new ways to effectively use social media, there are still many very successful industrial B2B companies who have either no or very little presence in social media. The purpose of this study was to examine how the most successful companies in the industrial distribution market segment use social media, and then to compare such companies to both the top industrial manufacturers and the Fortune 500 companies, regarding how they use social media.

LITERATURE REVIEW

The current study examines the use of social media in a B2B industrial distribution market. As such, it is important to understand the history of how social media has so rapidly infiltrated the business world. Further, understanding the migration of the Millennial generation to the workforce is important to fully explain the magnitude of the social media trend in the business environment.

Social Media

Social media, as understood today, is simply a means of transmitting and/or sharing information electronically with others. The original social networking sites developed in the 1990s, such as SixDegrees, MoveOn, BlackPlanet, and others, provided a portal where people could connect and share information via the Internet. By the early 2000s, numerous social media sites began to emerge. Many of these sites were specifically designed for people and organizations with common interests (e.g., music, sports, education, movies). This electronic communication forum was originally developed for individuals, but soon the business world took advantage of this new form of communication. A brief chronology of some of the more common social media sites (Junco, Heibergert, & Loken, 2011) follows:

TABLE 1: Social Media Chronology of Past and Current Forums

Year	Social Media Site	Notes
1997	SixDegrees	One of the original social media sites. Now defunct.
2001	Friendster	One of the first in the social networking space to reach over 1 million users.
2002	Skyrock/ Skyblog	Skyblog was one of the original blogging sites. Based in France, now called Skyrock
	LinkedIn	The first social media site designed for business and professional networking. In 2015, currently has over 400 million users.
2003	Myspace	From 2005 to 2008 was largest social media site. Has been in decline since.
2004	Facebook	Has over 1.2 billion active monthly users. One of the largest social media sites used by both businesses and individuals
2005	Yahoo!360	Gained a wide, global audience, but ultimately failed and closed in 2009
	YouTube	This video-sharing website has gained wide use among both business and individuals. Business has used this site to upload and share product and instructional videos

TABLE 1 continued: Social Media Chronology of Past and Current Forums

2006	Twitter	Allows users to use short, 140 character messages. Has more than 500 million users.
2007	Tumblr	More of a blogging site. The use of blogging is slowly declining among business users; therefore, this site is not a common among business users.
	Glassdoor	Collects and reports company data, such as salaries and employee reviews
2010	Instagram	Provides users mobile photo sharing and video sharing capabilities.

B2B companies have become quite proficient at the use of digital marketing during the past two decades. Using digital channels, such as the internet, wireless, and mobile communications, companies have learned how to communicate and transact business with a wider range of customers. However, the lines between social media and digital media are often blurred, as the elements of social media are "increasingly integrated into the established interactive digital media environment" (Jarvinen et al., 2012). While B2B companies have become quite capable at adopting all manner of digital marketing devices, such as sales and marketing support, email and other digital commercials and newsletters, and even e-commerce, these same companies have found it difficult to transfer this success into social media. Countless B2C companies have found tremendous success using social media tools to promote either their company or products. Some of these companies include T-Mobile, Taco Bell, GoPro, Pizza Hut, JetBlue, Dunkin' Donuts, and others. But the social media experience of these mass-market companies has not been transferred to the industrial B2B market, which generally has a more limited market.

Millennial Generation

According to recent population projections by the United States Census Bureau, in the United States alone the millennial generation (otherwise known as Gen Y, born between 1981-2000) reached an estimated 75.3 million people in 2014, surpassing the population of Baby Boomers (born between 1946-1964). The Gen X population (born between 1965-1980) is also expected to outnumber the Baby Boomer generation by 2028 (Fry, 2015). This change in demographics has had a significant impact on the way B2B companies conduct business. The Millennial generation has grown up in the digital age; they are accustomed to searching, sharing, and acquiring information from the Internet (Khan, 2009). Millennials are quick to research product quality, features/benefits, availability, and price of consumer products prior to purchase. As one of the largest consumer groups in the history of the United States, Millennials will have a profound impact at all levels of the business sector (Kim & Ammeter, 2008). Since technology habits developed as retail consumers (e.g., searching for pricing, product information) generally transfer to the workplace, it is reasonable to expect that the technological expertise of the Millennial generation will, in large part, determine marketing strategies for many companies (Hanford, 2005; Valentine & Powers, 2013).

Compare this information to that shown in Table 1. The most common social media sites today were developed while Millennials were still fairly young. Millennials grew up with cell phones, wireless technology, and extreme connectedness. They get their news from their phone. They shop for all manner of goods and services on the Internet. They are comfortable with sharing personal information on their blogs, on Facebook, on LinkedIn, and other social media sites. And they frequent these sites often. According to Zephoria (2016), a digital marketing consulting firm, 1.01 billion people log onto Facebook every day; there are 1.39 billion active users; the most common age demographic is ages 25-34 (29.7%); the highest traffic occurs during the middle of the week, between the hours of 1-3pm; and 50% of the 18-24 year old users check their Facebook immediately upon waking up. The numbers are staggering, and illustrate why marketing professionals continue to search for ways to tap into this tremendous marketing opportunity.

B2B Social Media Marketing Strategies

B2B company executives understand how powerful social media can be, yet continue to either underallocate funding (or worse to allocate nothing) to promote and develop social media strategies within the company (Kietzmann et al., 2011). This lack of foresight may be due, in part, to a lack of understanding about what social media is, how it can be implemented, and what it can do for the company (Kaplan & Haenlein, 2011). Ideas and strategies have been developed and proposed for company executives to understand and implement an effective social media policy (Kietzmann et al., 2011), and even though it is beyond the scope of this study to drill down into the different models developed, numerous authors and researchers have developed thorough social media return on investment (ROI) financial models (see Blanchard, 2011; Powell, Groves, & Dimos, 2011). Yet, despite the research, despite the success that many of the aforementioned B2C companies have experienced with social media, other companies in the industrial B2B market sector continue either to not use social media at all, or use it marginally.

Cardon and Marshall (2015) describe social media business enthusiasts as those who "emphasize that enterprise social media represent a new way of communicating and collaborating that is more interactive and bottom-up." Millennials understand social media as a way of communicating and learning effectively; it is almost a way of life for the Millennial generation. This constant interface with social media can be a phenomenal marketing tool, and social media business enthusiasts try to capitalize on this tool. But many in the Baby Boomer generation are more social media realists, viewing new technology on a risk vs. reward basis. For many of these executives, many of whom are of the Baby Boomer generation, the benefits of using social media do not outweigh the cost and other risks.

This study seeks to analyze the use of social media in the industrial distribution market sector, as compared to the industrial manufacturing market and the Fortune 500 companies. The purpose was to (a) determine if companies have a social media presence located directly on their web page, (b) determine if the social media sites on these company web sites are active or inactive, and (c) to compare the MDM Industrial Distribution Top 40 companies to the Industry Week Top 50 industrial manufacturers, and then to compare both of these to the Fortune 500 list of companies.

METHODOLOGY

The leading independent research agency in industrial distribution is Modern Distribution Management (MDM). Each year MDM surveys company officials and ranks the leading industrial distributors in 15 different industrial distribution market sectors, as well as the top 40 overall. This study uses the publicly available MDM data to analyze the use of social media by these top industrial distributors (MDM, 2015), (see Table 2 on page 22). In a similar survey, Industry Week publishes a list of the top 50 manufacturers in the United States. The current study evaluated the top 40 distributors (as rated by MDM), and then the top 40 manufacturers as identified by Industry Week's 2015 Top 50 Best Manufacturers (Industry Week, 2015), (see Table 3 on page 23), as well as the Fortune 500 list of companies.

Many of the companies represented on the MDM list are publicly traded, allowing for the collection of financial and employee information. Other companies on the MDM list are privately held, making the collection of financial and employee information difficult to obtain. All companies on the Industry Week list are public manufacturers. For each company represented, annual sales and the number of overall employees was determined. These numbers provided a good gauge regarding the size and breadth of each company. For example, some of the listed distribution companies are smaller, regional companies. A small component of the research was to ascertain if such smaller companies had a more aggressive social media campaign than did the larger companies.

Once annual sales and employee information were collected, social media information was collected from the primary website of each company. The social media sites used to gauge the companies' usage and activity were Facebook, LinkedIn, and Twitter. If the company had any of these social media sites listed on their primary web page, each social media site was viewed to determine if the company was active, or inactive, with the site. To be an active social media user, the authors determined that there must be new content on the site within the previous seven days, with a consistent stream of new content posted on the site.

TABLE 2: The companies analyzed in the Top 40 list of Industrial Distributors includes (MDM, 2015)

1	Wolseley Industrial Group	21	Bearing Distributors In.
2	W.W. Grainger	22	The United Distribution Group
3	HD Supply	23	Global Industrial
4	Airgas	24	SunSource
5	MRC Global Corporation	25	Turtle & Hughes
6	Motion Industries	26	Wajax Industrial Components
7	The Fastenal Company	27	BlackHawk Industrial
8	DistributionNOW	28	SBP Holdings Inc.
9	Sonepar Industrial	29	AWC Inc.
10	MSC Industrial Supply	30	Gas and Supply Co.
11	Applied Industrial Technologies	31	DGI Supply
12	WinWholesale Inc.	32	FCX Performance
13	McMaster-Carr	33	RS Hughes Co.
14	Edgen Group	34	Lawson Products
15	Wurth – Americas	35	Hisco
16	Interline Brands	36	Ryan Herco Flow Solutions
17	DXP Enterprises	37	Hydradyne
18	Kaman Industrial Technologies	38	OTP Industrial Solutions
19	ERIKS North America	39	Kimball Midwest
20	F.W. Webb	40	Womack Machine Supply

RESULTS

The findings of the research are shown on pages 24-25. First, the results of the industrial distribution companies are shown in Figure1, second, the industrial manufacturer and Fortune 500 data are shown in Figure 2, and finally the data from each is compared in Figures 3.

Industrial Distributors

Of the top 40 industrial distributors analyzed, 24 (or 75%) had some form of social media presence on their primary, or home web site. Of these 24 companies, only 17 (43%) had a presence on all three sites; Facebook, Twitter, and LinkedIn. Further, of these companies with some sort of social media presence, only 14 (35%) of them were active social media users (as defined earlier); the rest of the companies had varying levels of activity, ranging from the most recent update of three weeks to over three years. Those companies who are active on social media show varying levels of marketing-related material listed on their social media sites. This suggests that 25% of the top industrial distributors did not have any social media presence, and a total of 55% of the top distributors in the country do not actively engage

TABLE 3: The companies analyzed in the Top 50 of Industry Week's 2015 Top 50 Best Manufacturers includes (Industry Week, 2015):

1	Polaris Industries Inc.	**26**	Colgate-Palmolive Co.
2	Apple Inc.	**27**	FMC Technologies Inc.
3	Northern Tier Energy LP	**28**	Rockwell Automation Inc.
4	Monster Beverage Corp.	**29**	Coach Inc.
5	Deluxe Corp.	**30**	Gentex Corp.
6	Western Refining Inc.	**31**	Mead Johnson Nutrition Co.
7	Sanderson Farms Inc.	**32**	Altria Group Inc.
8	Hershey Co.	**33**	Hormel Foods Corp.
9	Sherwin-Williams Co.	**34**	IBM Corp.
10	Toro Co.	**35**	Estee Lauder Cos. Inc.
11	Microsoft Corp.	**36**	Cummins Inc.
12	NewMarket Corp.	**37**	Oracle Corp.
13	Oasis Petroleum Inc.	**38**	Renewable Energy Group Inc.
14	Pilgrim's Pride Corp.	**39**	Gilead Sciences Inc.
15	Westlake Chemical Corp.	**40**	Western Digital Corp.
16	Qualcomm Inc.	**41**	Borg Warner Inc.
17	Packaging Corp. of America	**42**	Keurig Green Mountain, Inc.
18	IDEXX Laboratories Inc.	**43**	Wabtec Corp.
19	Fossil Group Inc.	**44**	Lockheed Martin Corp.
20	Thor Industries Inc.	**45**	Skyworks Solutions Inc.
21	Mettler-Toledo International, Inc.	**46**	Wabash National Corp.
22	Nike Inc.	**47**	Linear Technology Corp.
23	Alon USA Partners LP	**48**	Middleby Corp.
24	Lear Corp.	**49**	Nordson Corp.
25	Donaldson Co. Inc.	**50**	Marathon Petroleum Corp

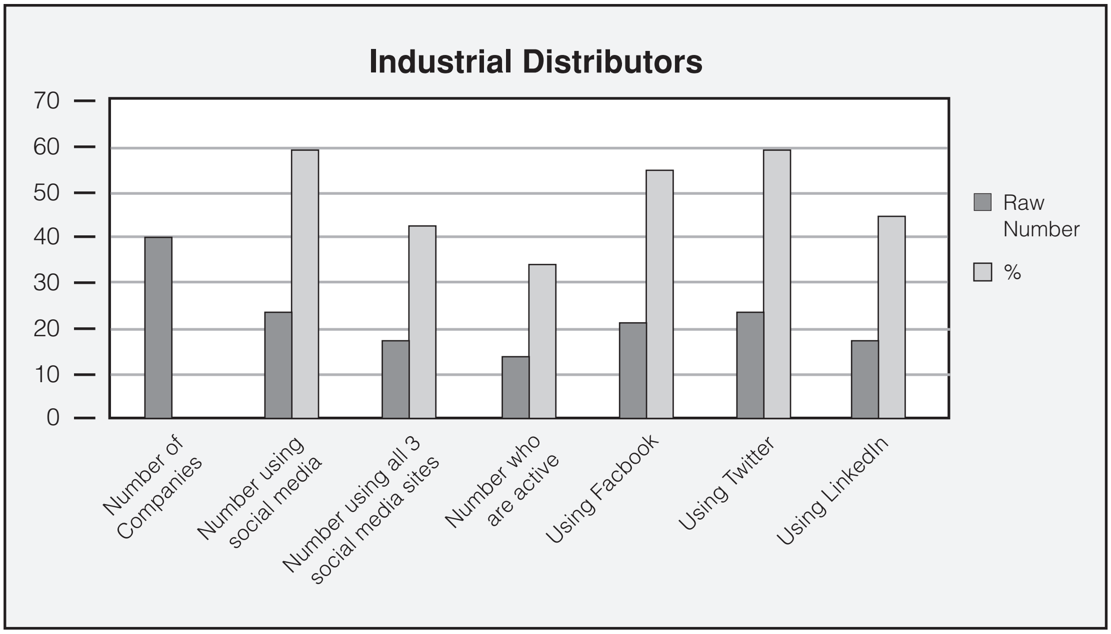

FIGURE 1. Top 40 Industrial Distributors Use of Social Media (MDM, 2015)

The ranking of the Top 40 Industrial Distributors by MDM (2015), Table 2 was by annual sales volume; Wolsley Industrial Group, with an annual sales of $11.9 billion, was in the top position, and Womack Machine Supply, with annual sales of $185.1 million, was in the last position. Number of employees is representative of associated annual sales: Wolsley with 22,810 employees and Womack with 290 employees. Despite the wide variance in annual sales and employee count, neither sales nor employee count seemed to have an impact on whether an industrial distribution company had a social media presence, and if the company did have a social media presence if the site was current and active. Figure 1 illustrates both the number of companies, and percentages of companies who use Facebook, Twitter, or LinkedIn.

Industrial Manufacturers

Although the companies listed in the Industry Week Top 50 represent a wide cross-section of industries, from sporting goods to pharmaceuticals to industrial products and others, the list is representative of what manufacturers think about the use of social media. Table 3.

Results, as shown in Figure 2, for the top industrial manufacturers were slightly different than that of industrial distributors. The data revealed that 33 (or 66%) of the top manufacturers have a link to social media on their home web page. Of these, only 16 (or 32% overall) had links to all three of the social media sites, Facebook, LinkedIn, and Twitter. The companies with a social media presence, even if it was only with one or two of the subject social media sites, seemed to be quite active with keeping their site current: 31 (or 62%, overall; 94% of all the social media users) of the manufacturers who had a social media presence had been actively engaged in updating their social media sites within the past seven days.

Each year Fortune magazine identifies the 500 largest corporations in America, referred to as the Fortune 500. Because of the influence of these Fortune 500 companies, a number of studies have examined the use of social media by them. It is interesting to note that in 2015, nine Fortune 500 companies did not use any form of social media. Figure 3 illustrates that Twitter is more popular than Facebook among these Fortune 500 companies by a measure of 78% to 74%, Glassdoor is rapidly becoming nearly as popular as LinkedIn as a business tool (87% usage vs. 93%), corporate blogs continue to decrease, and Instagram is becoming increasingly popular among business users (Barnes, Lescault, & Holmes, 2015). This data seems to corroborate what was found with the Industry Week Top 50 industrial manufacturers.

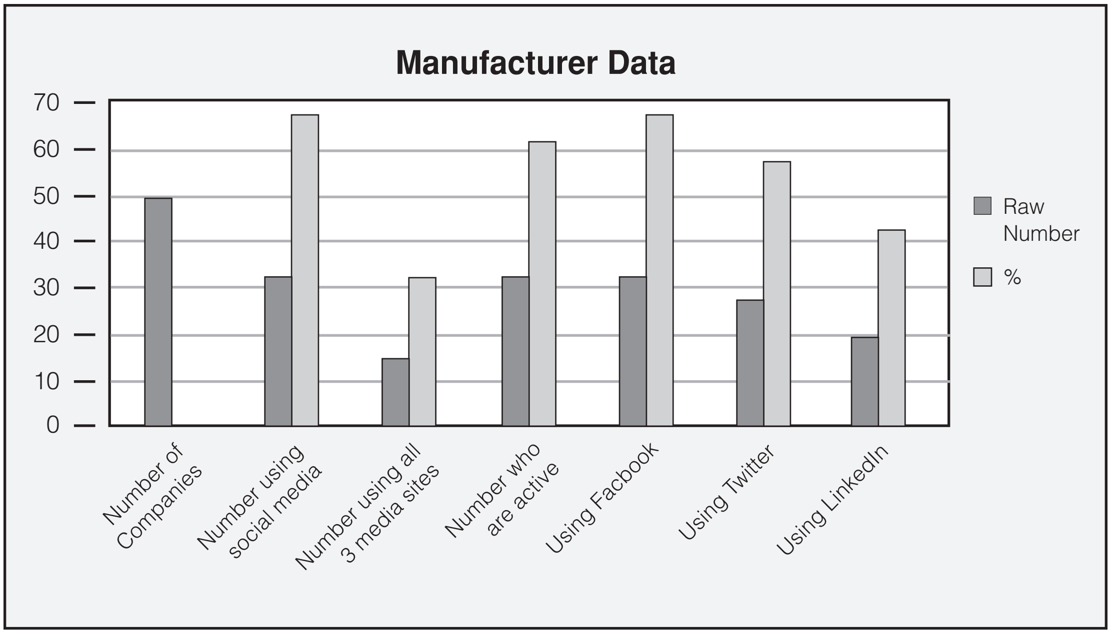

FIGURE 2. Top 50 Manufacturer's Use of Social Media (Industry Week, 2015)

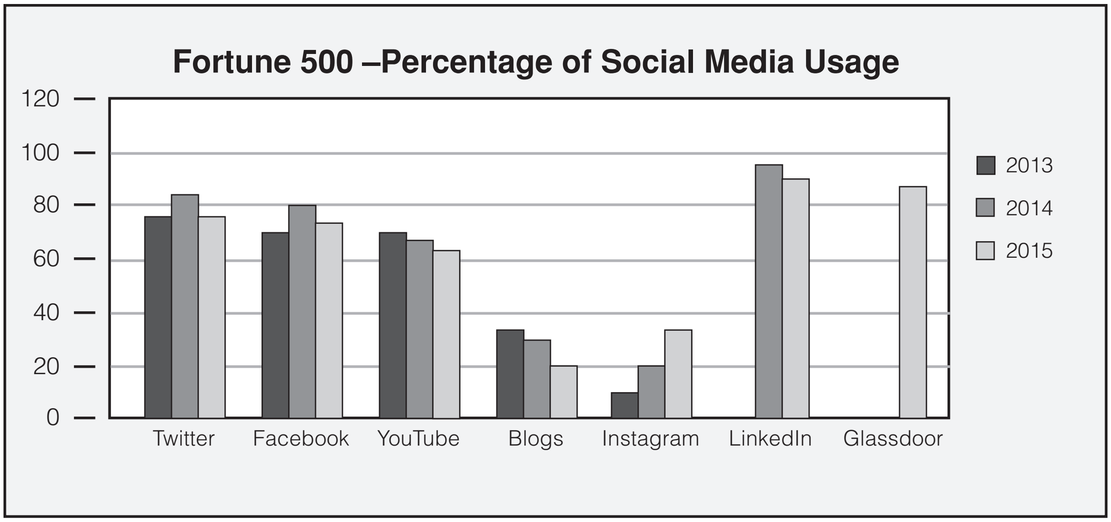

FIGURE 3. Fortune 500 Corporate Social Media Usage (Barnes et at., 2015)

CONCLUSION

It is interesting that some believe the fastest way to grow a company in the 21st century is through social media (Edosomwan, Kalangot-Prakashan, Kouame, Watson, & Seymour, 2011). Although it is clear that B2C companies have learned how to capitalize on the marketing opportunities that social media offers, it is less clear about the value of social media in an industrial setting where the overall market is much smaller.

There are other many circumstances that dictate whether a company engages in social media as a form of customer contact, marketing, or other sales strategy. For example, for a company that sells a very complex, engineered product, having a social media presence may not be necessary. Similarly, for a company that sells either custom systems or automation solutions, it may be difficult to precisely articulate the need for social media. Face-to-face, interpersonal relationships with the customer in these cases may be the best way to communicate regarding products or services to these customers. In contrast, a company whose products are commoditized, with a larger potential market, social media may be a cost effective way to communicate with the global market.

Another important factor may be tradition and firm size. In a study of industrial firms, Jarvinen et al. (2012) found that long-standing digital marketing tools such as emails, digital news letters, and other forms of digital marketing are perceived to be more effective than social media tools. Although this same study by Jarvinen et al. (2012) found that social media was more important to larger companies than to small to medium-sized firms, the data reviewed in this study did not seem to support this notion. Social media was used across all sizes of companies in the top 40 industrial distributors.

This sort of data, though interesting to highlight trends, is certainly not causal. Companies shown in all Figures 1-3 are highly successful in their markets. Some choose to use social media as a means to showcase products, services, opportunities, and other news associated with their respective company, while others choose not to participate in social media; yet, are highly successful. There may be some wisdom in not participating in social media if upper management is not committed to the process of keeping content current. For example, as Edosomwan et al. (2011) stated, social media is meant for conversation and information. If customers who actively use social media believe that they can get the current, up-to-date news about products, features, sales, and other information about a company and its products using social media, they may be very disappointed if that particular social media site is not maintained and kept current. Clearly, it takes commitment from corporate administration to provide the sort of financial and personnel resources necessary to keep all forms of social media current. Social media is a cost effective method of marketing a companies' brand (Paridon & Carraher, 2009), but the company must dedicate resources to keep sites current and to respond to customers' responses. If the commitment is not there, it just may be better to not use social media at all.

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STEM in General Education: Does Mathematics Competence Influence Course Selection

By Mary C. Enderson and John Ritz

ABSTRACT

Many students enroll in college programs to prepare for their future careers. All are required to complete general studies courses. At one university, technology and STEM courses fulfill a part of the natural science and technology general education requirements. This study uses a survey design to explore why 332 students chose to enroll in a STEM technology course. Results found most enroll because their advisor suggests the course, it meets a general education major requirement, and the course is offered at a convenient time. Fewer enroll in the course because they would like to find out more about STEM fields, be exposed to potential careers, or because of the implicit need to study STEM subjects. Student mathematics skills were analyzed to determine if these skills influenced their choice for selecting this technology STEM course.

Keywords: STEM in general education, STEM and mathematics, elective selection

INTRODUCTION

STEM is an acronym that has been discussed and tied to the economy and education. Spurred by the economic recession of 2008, policy leaders around the world believe there is a need to increase the number of science, technology, engineering, mathematics, and medical graduates from colleges and universities (Gates & Mirkin, 2012). Competitiveness through innovation seems to be a key in keeping economies growing and people working – working at well-paying jobs. Within the evolving world marketplace, countries that develop technological innovations thrive in the marketplace and drive economic development (e.g., fuel cell vehicles, next-generation robotics, precise genetic engineering techniques, emergent artificial intelligence, distributed manufacturing, and "sense and avoid" drones) (Meyerson, 2015).

World leaders want their citizens to compete for good jobs within the global economy. To do this, the emerging workforce will need advanced knowledge and skills. The improved study of science, technology, engineering, and mathematics can create pathways that provide the education that leads to the creation of new products, particularly knowledge of technology (Committee on Prospering in the Global Economy of the 21st Century, 2007). According to the National Academies, many innovative products result from "four percent of the nation's work force [which] is composed of scientists and engineers" (Rising Above the Gathering Storm Committee, 2010, pp. 2-3). Their innovations often support the employment of most other workers.

Why are so few students preparing for or choosing to major in STEM subjects? Some researchers believe the image of STEM careers and STEM subject difficulties are two prohibiting factors (Jahn & Myers, 2015; Wyss, Heulskamp, & Siebert, 2010). The study of advanced levels of mathematics has been reported as a detriment to more students studying STEM subjects (Petroski, 2015). If students select to enroll in STEM elective courses at the university level, why did they choose to do this? Because universities are acknowledging that their responsibilities extend beyond producing the next generation of scientists, technologists, engineers, and mathematicians, some are recognizing that the challenge is to equip students with the scientific and technical literacy and numeracy required to play meaningful roles in society (Gates & Mirkin, 2012). In some instances, these roles may not be directly tied to STEM careers but to other professions that may benefit from general coursework in STEM studies. Such experiences may find a place for general education elective courses designed to provide general STEM knowledge.

Over a century ago, Dennett (1886) did not understand the value in students' taking elective university courses unless these originated from a reasonable cause. At the university where this study was undertaken, there was a major shift in the general education curriculum in 1994. Prior to this time, the goal of general education was to provide a liberal education for all. During the revision, the general education review committee chose to re-design the general studies curriculum to be more focused on student needs and the knowledge students would need to be successful in their selected major. After the redesign, composition remains a cornerstone of the curriculum, as does mathematics, science, and the social sciences. However, expanded philosophical views were woven into the new general studies curriculum. One goal was to *develop an understanding of the natural sciences and technology and their contributions to human culture.* In addition to this goal, an objective was added: *students should understand the nature of technology and its impacts on society and the environment.*

Using this revised goal as leverage, one department created a course titled *Technology in Your World.* It is one of several courses students can select from to fulfill the technology requirement. This course has proven to fulfill *a reasonable cause* (Dennett, 1886) and it is often selected by students to meet the technology literacy requirement. According to the university undergraduate catalog, the course is described as “an overview of the resources and systems of technology. Emphasis is on impacts that technology has on individuals and their careers. Activities explore the evolution of technology, its major systems and their impact on individuals and their careers” (Old Dominion University, 2015, p. 466). Although this course focuses primarily on the study of technology, aspects of science, engineering, and mathematics are introduced during laboratory investigations. This course includes an overview of major technological systems and it requires hands-on activities designed to show students how technology is applied in various careers. Some university majors fulfill this requirement through technology courses required by their major program.

This study investigated why students chose to enroll in this university general education course. Elective courses are used to increase students’ levels of awareness, acceptance, and understandings (Evans, 2006). Research by Ting and Lee (2012) explained that students select electives for various reasons, including (a) perceived interest of the subject, (b) perceived difficulty of subject material, (c) perceived leniency of the lecturer, (d) exposure to future career skills, (e) influence of others, (f) popularity/personality of lecturer/quality of teaching, (g) day of the week and meeting hour, (h) reputation of the university, (i) suitability of the subject, and (j) size of class. This study explored these variables to determine students’ reasons for selecting such a course. It also explored students’ backgrounds in high school mathematics and the depth of mathematics they had completed at the university level prior to selecting this course.

LITERATURE REVIEW

This study’s review of literature explores STEM and its perceived relationship to the development of the economy. It also reviews technological literacy and its relationship to STEM. Finally it investigates the relationship of mathematics knowledge and abilities to the success of STEM majors. These areas are presented because they are relevant to a student’s studying STEM through university coursework and the way STEM can support or challenge the student’s selection of a STEM major or preparation for other future careers.

STEM and the Economy

The post WWII economy grew and required increased labor in the manufacturing and construction industries (Conte, Karr, Clark, Hug, & Manning, 2001). There was demand for consumer and industrial products and housing as the American economy grew. Muscle and a high school education did well for laborers. The Cold War Era saw a demand for higher education for engineers and scientists who would develop systems to process and mass produce food, automobiles, appliances, and electronic products, and then develop the systems to move products and people around the country and world. The growing economy demanded an increasing reliance on advancing technologies. Engineers and scientists produced lightweight metals and plastics, jetliners, high-rise buildings, and food to feed the increasing population.

Education in science, technology, engineering, and mathematics has continued through various funding streams since the Cold War (Haugsbakk, 2013). In addition to government efforts, business and industry, and their foundations, needed additional STEM education to provide the innovative workers required in the nation. According to Gates and Mirken (2012), insufficient numbers of students are majoring in science, engineering, and medical professions. The technology workforce is also in short supply. In addition to college graduates, there is demand for two-year technical graduates and graduates of career and technical education programs. It is estimated that 600,000 skilled workers are needed for current manufacturing jobs (Sirkin, 2013). STEM skills continue to be in demand.

Technological Literacy

To function effectively in society, citizens must have knowledge of the technology around them. They should understand some technologies at the macro-level, and they should be familiar with specific technologies needed in their life and work pursuits. For instance, it is good to understand what STEM cell research is and that it might someday improve your life (macro-level). It is also important that a person become more familiar with a computing system at the micro-level (e.g., which system is most appropriate to purchase, how to change a printer cartridge to continue to have quality output). These are literacies – technological literacies.

To function in a society, a person understands spoken words, reading and writing, and general mathematics (general literacies). In the U.S. Workforce Investment Act of 1998, literacy is defined as "an individual's ability to read, write, speak in English, compute and solve problems at levels of proficiency necessary to function on the job, in the family of the individual and in society" (p. 131). In addition to these general literacies, some educators believe all people need:

> A new form of literacy – a technological literacy . . . This is a vital necessity if citizens are to participate in assessing and determining the relationship of technological systems to human needs. To function in this role requires that all citizens be conversant in the language of technological systems and comprehend basic concepts of the dynamics of the interrelated systems for all levels of society. (DeVore, 1980, p. 338)

Technological literacy is defined as "the ability to use, manage, understand, and assess technology" (ITEA, 2000, p. 242). However in practice, technology has at times been focused on developing technical expertise, instead of how useful or pertinent the technologies can be (Ginestié, 2008). To "understand, use, assess, and manage technology" (ITEA, 2000, p. 242) is much different than to develop expertise in a few technologies, such as robotics and machining. According to Pearson and Young (2002):

> Technological literacy is not the same as technical competency. Technically trained people have a high level of knowledge and skill related to one or more specific technologies or technical areas . . . a technologically literate person would not necessarily require extensive technical skills. Technological literacy is more of a capacity to understand the broader technological world rather than an ability to work with specific pieces of it. (pp. 21-22)

Because much of the world continues to experience new technologies and changing economic situations, and the general higher education system is almost void in explaining these developments and how or if they should be used for the betterment of society, such knowledge and abilities should eventually become one focus of education through technology studies programs. Pearson and Young (2002) stated that "technological literacy – an understanding of the nature and history of technology, a basic hands-on capability related to technology, and an ability to think critically about technological development – is essential for people living in a modern nation . . ." (pp. 11-12). Such people have knowledge of technology and are capable of using it effectively to accomplish various tasks. They can think critically about technological issues and act accordingly. Technological literate people would possess knowledge, ways of thinking and acting, and capabilities that assist them as they interact with the technology found in their environments. These knowledge and skills align with those specified in *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000). These types of outcomes were used at the institution where this study took place. Faculty developed a general technological literacy course for a general population of students, and they worked to have it fulfill the science and technology requirement of the university's general education program. In the class, technological concepts and principles were taught, and students applied this knowledge through laboratory activities (see Ritz, 2011 for a detailed description of the course outcomes and assessments).

Mathematics and STEM

The role of mathematics in STEM is often seen as a tool to solve problems in science, technology, and engineering. Mathematics as a discipline involves numerical, spatial, and logical relationships used to make sense of or solve problems (Vilorio, 2014). Although the study of mathematics as a college major is not widespread, the concepts and ideas of mathematics permeate across various disciplines. Mathematics finds its place in many of the non-science fields, including art, business, communication, criminal justice, language, music, recreation, and sports management. Work in these fields includes mathematics concepts focused on computations as well as applications in areas centered on budgets, rhythms and beats, shapes and colors, logic, accident evidence and data, tracking scores and game statistics, and recreational terrains and geographical data. Students who major in such non-science fields are often required to take one to two mathematics courses typically focused on college algebra and statistics.

STEM as a career choice or some component of STEM as a major typically begins prior to university study. High schools usually offer courses in advanced mathematics (e.g., calculus, AP calculus) that provide a solid foundation for students entering a university with an interest in one of the STEM disciplines. Mathematics provides one with critical thinking skills that involve studying problems from different angles as well as using problem solving techniques to find solutions. It teaches a person how to approach tasks methodically, pay attention to details, and to think abstractly – qualities that many employers appreciate (Torpey, 2012). Being able to discuss the mathematics used in solving problems requires a sound understanding of concepts and how they connect across various disciplines.

The United States has witnessed a decline in the STEM workforce, which causes a void in STEM careers and job opportunities. Studies and reports document the challenges students face in acquiring success in mathematics as they complete high school and consider enrollment in college/university studies or progression into the labor market. High-level mathematics in high school is a powerful predictor of success in work and life regardless of a person's choice to attend college or enter the workforce (Peckham, 2015). For a number of years, the ACT, SAT, and the Educational Policy Improvement Center have been tackling issues surrounding career and college readiness. Mathematics is one area identified in several reports that indicate students need a thorough understanding of basic mathematics concepts as well as problem solving to interpret, understand, and analyze real problems (Conley, 2011) both at the college level and in the workplace.

Mathematics is one strand of STEM literacy, which involves weaving together knowledge for each discipline – science, technology, engineering, and mathematics. In the case of mathematics, it is an individual's ability to understand the role of mathematics in the world around him/her and to use the mathematics to make sound decisions. Such mathematics literacy is defined as, "An individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgments, and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen" (OECD, 2009, p. 84). In addition, the OECD (2013) recently established that literacy, numeracy, and problem solving skills were linked to positive work outcomes, including employment and earnings. Regardless of whether a student declares a major in mathematics or some other discipline, being mathematically literate is of utmost importance in resolving problems and situations and to produce citizens who are ready for today's workforce. This study sought to see if mathematics competence had a relationship to students' decisions to enroll in this STEM technology course.

RESEARCH PROBLEM AND QUESTIONS

The problem of this study was to determine the influence that mathematics competence has on students' decisions to enroll in STEM courses. This problem arose because of the curiosity of the researchers working at a university and meeting students who change majors due to their perceived weaknesses in mathematics.

To guide this study, the following research questions were developed:

> **RQ1:** What prompts students to enroll in a general education STEM course?
>
> **RQ2:** Is there a relationship between student competence in mathematics and the enrollment in STEM courses and majors?

METHODOLOGY

With such a strong STEM push in future careers and workforce opportunities, researchers were interested to know more about the mathematics background of students in this specific lower level STEM course. Because mathematics plays a vital role in STEM, the researchers believed that students who would be enticed to take the

STEM general education course would also have strength in mathematics either through high school coursework or through their identification as a STEM major. Thus, the researchers adopted a quantitative study design. The research design selected for this study was the survey method, a nonexperimental quantitative research tool. Fraenkel, Wallen, and Hyun (2012) identified the survey as a method to "describe the characteristics of a population" (p. 393). These authors noted that in other types of research "the population as a whole is rarely studied" (p. 393), the survey method allows for a "carefully selected sample of respondents" (p. 394) to be surveyed, and a "description of the population is inferred from what is found out about the sample" (p. 394). For purposes of this study, a cross-sectional survey was administered to gather information from a predetermined population at a predetermined point in time. Gay, Mills, and Airasian (2012) noted that cross-sectional designs are "effective for providing a snapshot of the current behaviors, attitudes, and beliefs in a population" (p. 185). Creswell (2012) stated that a cross-sectional survey design has the "advantage of measuring current attitudes or practices" (p. 377).

Participants and Data Collection Instrument

The participants involved in this research were undergraduates enrolled in a STEM 110 level course, *Technology and Your World,* which was designed for a general population. This general education course met a university technology studies requirement and was strongly recommended to students by various major advisors. During the fall term 12 sections of the course were offered with approximately 400 students enrolled. The university studied had a diverse undergraduate student representation: 55.9% White, 23.8% Black, 6.2% Hispanic, and 4.2% Asian. Fifty-five percent of the undergraduate population was noted as female (StateUniversity.Com, 2016). The university in this study was classified as a metropolitan research one university.

A survey was designed based upon the research questions and knowledge of elective course selection and mathematics performance found in the literature. The survey was distributed during the first week of classes, so influence by the various instructors who taught this course should have had little impact on student responses. Student participation in the study was voluntary. The survey was one page in length and was comprised of two parts. Part 1 asked students to select and rank their top three choices/reasons why they selected to take the course. Nine responses were listed: (a) Required for my major, (b) Interested in finding more about STEM fields, (c) Course offered at a convenient time (day and time), (d) Level of difficulty of the class, (e) Popularity of the instructor, (f) Exposure to future career skills, (g) Influence of others (peers, parents, advisor, others), (h) Reputation of the need to study STEM subjects, and (i) Class size influences my course selection. Part 2 of the survey focused on identifying participants' mathematics background that included prior high school mathematics courses and college-level mathematics coursework completed since entering the university. Part 3 asked for student major and if undecided, what discipline(s) the student was considering. Data were collected anonymously. The course instructors distributed surveys at the end of the first week of classes. Students who chose to participate placed completed surveys into an envelope when they exited the classroom and hence were nonidentifiable by the instructors and researchers. No identifying information was collected on the surveys.

DATA ANALYSIS AND FINDINGS

Out of the $n = 414$ registered students, 332 (N) returned completed surveys. According to Krejcie and Morgan (1970), an acceptable number of returns fall between 196 (given $n = 400$) and 201 (given $n = 420$), which more than meets the recommended sample size. The calculated confidence level for these data was 99% with a confidence interval of 3.2. Data, which were self-reported, from the 332 participants were used to address the research questions for this study.

The first research question was focused on the motivation of students who enroll in a STEM general education course. Participants were provided with nine choices to select from in responding to the question and were requested to identify up to three choices in rank order (e.g., 1, 2, and 3). The results show "required for my major" to be selected by 281 (84.6%) participants as a choice for taking the STEM technology course. After this preference, "course day and time" was next with 109 (32.8%) responses. Beyond these two selections, other options did not receive as many responses with several in the 80s – influence of others, level of difficulty of the course, and exposure to future career skills, followed by interest in finding out more about STEM, popularity of instructor, reputation of the need to study STEM, and finally class size. Table 1 identifies the choices and the number of respondents who selected each one and the percentage of respondents for each category.

TABLE 1:
Responses for Selecting the STEM Course

Responses	Number Selected	Percent
Required for my major	281	84.6%
Interested in finding more about STEM fields	79	23.8%
Course offered at a convenient time (day & time)	109	32.8%
Level of difficulty of the class	87	26.2%
Popularity of the instructor	56	16.9%
Exposure to future career skills	85	25.6%
Influence of others (peers, parents, advisor, others)	88	26.5%
Reputation of the need to study STEM subjects	49	14.8%
Class size influences my course selection	23	6.9%

In addition to studying reasons why students enroll in a STEM introductory course, the researchers were interested to determine if a relationship exists between competence in mathematics and interest/enrollment in a STEM course. Participants were asked to identify what mathematics courses they completed in high school as well as in college. The literature in career and college readiness indicates students who are interested in STEM fields need greater levels of mathematics prior to attending college/university (Gates & Mirkin, 2012). More than 60% (*N* = 202) of respondents indicated that they had taken both geometry and algebra 2 in high school. This signifies that the participants were academically beyond a secondary algebra 1 course of mathematics. From a college and career readiness perspective, such students would more than likely begin their mathematics coursework at or below the college algebra level, and thus would not have a strong mathematics background to seriously consider a major in STEM or a related STEM discipline.

Subsequent to geometry and algebra 2, approximately 33% (*N* = 109) completed a pre-calculus course and less than 17% (*N* = 56) completed a calculus course – some completing regular calculus and others completing advanced placement calculus. Such outcomes document a small number of secondary students who are well positioned for serious study of STEM in college or in the workplace. Other research has provided evidence that entering a university with more rigorous mathematics coursework prepares students for future study of STEM, which in turn can help fill the STEM pipeline (Tyson, Lee, Borman, & Hanson, 2007).

At the university level, researchers found that approximately 37% (*N* = 124) completed college algebra, while the next course that appeared with regularity was statistics at 30% (*N* = 100). Numbers were quite low for pre-calculus (*N* = 49) and calculus (*N* = 45), which supports the lack of mathematics completion in secondary school prior to university study. According to the data 11 participants took business calculus, which is appropriate for business majors rather than STEM majors. Overall, very little mathematics showed up for this particular sample, which compelled researchers to take a closer look at the college majors participants identified on the survey instrument. Non-science majors often do not enroll in advanced or upper level mathematics courses that are not a part of their program of study, whereas typically STEM majors take a significant amount of mathematics (usually through calculus).

The results were supported by two chi-square analyses of the data. The first analysis concentrated on STEM and non-STEM majors and the level of mathematics participants completed. Mathematics coursework was identified as high level if participants completed pre-calculus or higher level math courses and identified as low level if coursework was lower than pre-calculus. The result for this particular chi-square analysis was 37.276 (with one degree of freedom) and was significant at the $p < .01$

level; $\chi^2(1) = 37.276$, $p < .01$. This analysis confirmed that non-STEM majors were more likely to complete lower levels of mathematics coursework.

The second chi-square analysis focused on level of mathematics courses completed and the grades participants received for the noted coursework. Again, the level of mathematics courses was considered high level if participants had completed pre-calculus or higher courses. Regarding the grade aspect of this analysis, A's and B's were considered high level and C's, D's, and F's were considered low level. The result of this chi-square analysis (with one degree of freedom) produced 6.653 and was found to be significant at the p <. 01 level; $\chi^2(1) = 6.653$, $p < .01$. Thus, there appears to be a relationship between the level of mathematics courses taken and the grades received.

In addition to identifying the mathematics background students' possessed on the survey, participants were asked to identify the major or intended major. The top three programs identified through this STEM survey were Biology (*N* = 45), Criminal Justice (*N* = 41), and Psychology (*N* = 38). Out of these three majors, two fall in the College of Sciences, but they do not possess a heavy focus on mathematics coursework. In the case of Biology, students are not required to take mathematics coursework higher than pre-calculus or calculus 1. Psychology majors must take two 100-level mathematics courses (college algebra and elementary statistics). In both College of Science programs, the amount of mathematics is quite minimal and tends to fall at the lower end of the spectrum. The Criminal Justice program lies in the College of Arts and Letters, and, as is often the case, mathematics receives sparse attention. Criminal Justice majors are required to take an elementary statistics course, which also counts toward the completion of a 3-hour general education requirement. Thus, the three designated majors paint a picture of a low mathematics background of participants who enrolled in this STEM course. In addition to the three majors presented, 45 other majors were identified from survey data with a handful in areas such as chemistry, engineering, mathematics, physics, and modeling & simulations (*N* = 22) that required more advanced coursework in mathematics. See Table 2 for majors identified in the survey and how many participants were in each category.

TABLE 2:
Identification of Participants' Declared Majors

Major	Number of Participants *
Art	5
Biology	**45**
Civ. Eng./Civ. Eng. Tech.	7
Communication	31
Criminal Justice	**41**
English	6
Exercise science	7
Health sciences	5
Health services admin.	5
Human services	15
Mathematics	5
Nursing	8
Psychology	**38**
Speech path.	12
Sports management	21
Supply chain management	5
Therapeutic rec	5
Tourism management	9
Undeclared	16

NOTE: If less than 5 students indicated the subject as a major, it was not included in the table.

DISCUSSION, IMPLICATIONS, & RECOMMENDATIONS

This study investigated why students elect to enroll in a STEM university general education course and if their mathematics background had any influence on their taking such a course. Evidence exists that far too many students lose interest in science, technology, engineering, and mathematics in middle and high school; as a result they exit out of the STEM pipeline –

many even before arriving to college/university (Gates & Mirkin, 2012). It is unfortunate to witness as the "T" and "E" – Technology and Engineering – often are valuable ways to apply science and mathematics. As has been well documented, many students are unprepared for the demands and expectations of postsecondary education (Conley, 2003). In one study, faculty identified critical thinking and problem solving as primary areas in which first-year students needed greater improvement (Lundell, Higbee, Hipp, & Copeland, 2004). Since these processes are a major part of mathematics, researchers were interested in reasons why students take a STEM course as well as how the mathematics background fits in with the decision-making process.

In addition to concerns raised about lack of interest in STEM careers across the United States, other employers and businesses that are not STEM focused have expectations that align to similar concepts and ideas. The Association of American Colleges and Universities (AAC&U) carried out a survey among business leaders: in it employers were asked to assess emphasis colleges and universities placed on learning outcomes (Hart, 2006). The survey revealed that employers believe higher education institutions should do more to achieve learning outcomes in multiple areas to ensure future employees will be successful contributing members in today's global economy. In a list of their top priorities, it was documented that greater emphasis should be placed on (a) critical thinking and analytical reasoning skills and (b) science and technology. In both of these instances, a general education STEM course can provide all fields with such emphases (Hart, 2006).

This particular STEM course was designed to expose any student, regardless of his/her major, to future career skills in the STEM fields ($N = 85$; 25.6%), to provide more information about STEM fields ($N = 79$; 23.8%), and to understand the reputation of the need to study STEM subjects ($N = 49$; 14.8%). Interesting, none of these points appeared relevant to the participants in this particular study. It would be interesting to determine if these findings are common to future semesters of the course offering and if so, why or if not, why not.

As this study was designed and carried out, researchers believed that there would be a greater number of STEM majors in the sample surveyed. However, very few participants were STEM majors ($N = 73$). It would be of interest to determine what course(s) such majors are taking in the STEM areas and how their mathematics background prepared them for such courses.

CONCLUSIONS

With today's STEM movement, the job market is searching for potential hires in the fields of science, technology, engineering, and mathematics. For college and university students not majoring in these disciplines, a STEM course may translate into looking for ways to strengthen or "round out" their educational experiences for future job opportunities. Elective coursework, in and out of the major, is one option that may fit this scenario. In other instances, electives may be part of the university's general education courses that are designed to expose students to the sciences (including mathematics and technology), humanities, writing and literature, and history. Both situations serve the purpose in complementing a student's degree. As Hachtmann (2012) stated, "Whereas knowledge of disciplinary facts and concepts used to be the emphasis, now the focus of student learning is on broadly defined competencies to ensure that students are well equipped to be responsible citizens and professionals upon graduation" (p. 19).

This study occurred at one university using a course with 12 sections offered to students during one semester. In this particular study it was found that university students who took a STEM course were prompted to enroll in it as a result of advising and that their mathematics background really was not a factor. It was also determined that most students in the STEM course that was used for this study, lacked an advanced mathematics background and were not taking advanced mathematics courses. This helped answer the second research question as to whether there is a relationship between a student's competence in mathematics and enrollment in a STEM course. This study did not find a strong relationship for this particular STEM course. Such results indicate that providing students, regardless of their degree major, options to take lower level STEM courses may benefit them in the long run by exposing them to basic STEM concepts and ideas. In turn, future employers may consider such experiences valuable to their workplace preparation and technology studies courses into the curriculum for all. If this occurs, courses should be created with knowledge of the mathematics background of students. Advisors' recommendations and course schedules are also important factors to consider in the students' selection of these types of elective courses.

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Educators' Resistance to the Technology and Engineering Education Transition

By Kenneth L. Rigler Jr.

ABSTRACT

The purpose of the qualitative grounded theory study was to explore why industrial arts educators resisted organizational change to technology and engineering education. An exploratory, grounded theory method was used to identify new theory related to educators' resistance because the current literature did not provide a theoretical perspective about why industrial arts educators have resisted the change. The sampling frame was derived from a database of 379 secondary technology and engineering education teachers in the state of Kansas, and a sample size of 13 participants was needed to reach theoretical saturation of the phenomenon. The data for the study was collected through observations and face-to-face semi-structured interviews with in-service industrial education teachers. Data collected from the observations and interviews were analyzed using the three-phase classic grounded theory coding technique. Data analysis and interpretation resulted in the emergence of three substantive theories related to the study phenomenon: (a) inefficacious transition to technology and engineering education, (b) value for technical learning, and (c) industry demand-based change.

keywords: educator resistance, technology education, engineering education, industrial arts, grounded theory

EDUCATOR RESISTANCE TO THE TECHNOLOGY AND ENGINEERING EDUCATION TRANSITION

Technology and engineering education is a school discipline that has a century-long history of being redefined (Asunda & Hill, 2008). With each transition, the theoretical place and purpose of the discipline within the schools has been modified, which has created a growing gap between the discipline's theory and practice (Lauda, 1984; Wright, Washer, Watkins, & Scott, 2008). Even though program titles within the discipline have changed from industrial arts to technology and engineering education, there are still a significant number of secondary industrial arts educators who continue to teach from a traditional industrial arts curriculum (Kelley & Wicklein, 2009; Spencer & Rogers, 2006), and as a result they have resisted this transition (Sanders, 1997; Spencer & Rogers, 2006; Wright et al., 2008). Despite significant efforts from the International Technology and Engineering Education Association (ITEEA) to establish technology education as a broad-based academic core discipline for technology literacy, it has often remained as an elective under the umbrella of career and technical education (Dugger & Johnson, 1992; Wright et al., 2008). These discrepancies have created division among professionals in the field and confusion regarding the overall purpose of the discipline (Katsioloudis & Moye, 2012; Wicklein & Hill, 1996).

LITERATURE REVIEW

The highest ranked future critical problem for the technology and engineering education discipline reported by Katsioloudis and Moye (2012) was related to school counselors who did not understand technology and engineering education. This was not surprising because Kelley and Wicklein (2009) emphasized that technology education has a history of generating new program titles with little curricular changes. What started as manual training in the 1880s changed to manual arts in the early 1900s, then to industrial arts in the 1930s, then to industrial technology in 1970s, then to technology education in the 1980s, and then most recently to technology and engineering education in the 2000s. As the curricular focus and content has been modified with each name change, it has created ambiguity and confusion for all stakeholders involved in the discipline (Katsioloudis & Moye, 2012).

Technology Literacy as the Curricular Focus

Around the turn of the 21st century, the International Technology Education Association (ITEA) developed multiple publications to clearly articulate its purpose and focus for the discipline centered on educating all students for technology literacy. Relating to technology literacy, Ritz (2009) conducted a Delphi study with the ITEA leadership board with the purpose of articulating goals for the K12 technological literacy programs. The top five essential goals for technological literacy programs identified in the study included:

1. Describe social, ethical, and environmental impacts associated with the use of technology.
2. Become educated consumers of technology for personal, professional, and societal use.
3. Apply design principles that solve engineering and technological problems.
4. Use technological systems and devices.
5. Use technology to solve problems. (Ritz, 2009, p. 59)

A comparison between Ritz's (2009) study and the data collected by Bame and Miller (1980) as part of the Standards for Industrial Arts Programs project clearly articulated the differences between the former industrial arts purposes and the modern goals for technology education. In the Bame and Miller (1980) study, the middle and high school industrial arts teachers identified the top two purposes for industrial arts as (a) to develop skill in using tools and machines and (b) provide technical knowledge and skill. The emphasis of the industrial arts curriculum was clearly on skill development, whereas the top technology goals were focused on broad-based, knowledge-oriented concepts relating to technological literacy.

Engineering Design as the Curricular Focus

Throughout the 21st century, during the same time the ITEA leadership was articulating the discipline's role and purpose in teaching technology literacy, the leadership also began to introduce an additional curricular focus for technology education—engineering (Asunda & Hill, 2008; Pinelli & Haynie, 2010). In 2010, the ITEA changed its name to the International Technology and Engineering Educators Association (ITEEA) with the purpose of incorporating engineering education into the technology education curriculum (International Technology and Engineering Educators Association, 2010). To help clarify the relationship between technology and engineering, Custer, Daugherty, and Meyer (2010) conducted an emergent qualitative study and identified 13 engineering concepts generated from over 100 original themes. The study helped identify that in order to appropriately integrate a focus on engineering education, the curriculum would need to incorporate a higher level of scientific and mathematical concepts particularly in the areas of statics, dynamics, thermodynamics, stresses, deflections, and loads (Custer et al., 2010).

Career and Technical Education as the Curricular Focus

Career and technical education, formerly known as vocational education, has had a very real, yet covert relationship with technology and engineering education. The hidden relationship has most notably been due to the fact that the leaders of the technology and engineering education have worked for decades to differentiate and separate the two content areas (Kelley & Wicklein, 2009). However, the evidence from the literature has demonstrated a connection between technology and engineering education teachers and career and technical education (Kelley & Kellam, 2009; Moye, Dugger, & Starkweather, 2012; Wright et al., 2008). Many state departments of education have categorized technology and engineering education as a sub-category under the umbrella of career and technical education for several decades (Dugger & Johnson, 1992; Moye et al., 2012; Spencer & Rogers, 2006).

Another example of the relationship between career and technical education and technology and engineering education surfaced in Kelley and Wicklein's (2009) study as they examined the inclusion of engineering design in technology education's curriculum. The participants reported that the application of engineering design through the development of basic skills using tools was emphasized and not the application of math and science. Kelley and Wicklein (2009) interpreted this emphasis to indicate that a significant percentage of technology educators had not transitioned to the recommended broad-based engineering design curriculum and instead emphasized tool skill development more closely related with career and technical education.

The breadth of curricular focuses including technology literacy, engineering education, and career and technical education has created division amongst the professionals in the field and confusion as to the overall purpose of technology and engineering education (Katsioloudis & Moye, 2012; Wicklein & Hill, 1996). The quantitative results in the literature have indicated that a significant number of secondary industrial arts educators have resisted the transition to technology and engineering education and have instead continued to teach from a traditional industrial arts curriculum (Kelley & Wicklein, 2009; Spencer & Rogers, 2006; Wright et al., 2008). However, there are gaps within the literature providing an explanation as to why the educators have resisted the transition to technology and engineering education.

METHODS

The purpose of this qualitative grounded theory study was to explore why the industrial arts educators resisted the organizational change to technology and engineering education. Consistent with a grounded theory research design, the study was broadly guided by the following research questions:

Q1. What types of resistance have the Kansas industrial arts educators demonstrated toward the transition to technology and engineering education?

Q2. Why have the Kansas industrial arts educators resisted the organizational change to technology and engineering education?

An exploratory, grounded theory method was used to identify new theory as it allowed for the collection of the thoughts and feelings related to the educator resistance to change (Corbin & Strauss, 2008; Patton, 2001). A grounded theory research design is often used for the purpose of building theory rather than testing it (Glaser & Strauss, 1967; Urquhart, 2013), and it was most appropriate for the current study because the current literature base did not include a theoretical perspective for this phenomenon. The target population for the study was licensed industrial arts and/or technology education teachers in the state of Kansas who were currently teaching a traditional industrial arts-based program with a minimum of five years of teaching experience. The criteria for a minimum of five years of teaching experience was established in order to obtain the beliefs and values of experienced educators who were trained before, during, and after the transition from industrial arts to technology education. The sampling frame was derived from a database of 379 secondary industrial arts/technology education teachers in the state of Kansas. Maximum variation purposeful sampling and theoretical sampling techniques were used to increase the potential for naturalistic generalization and extrapolation of the study findings (Patton, 2001) and to select participants that provided related variations to the concepts emerging in the data (Corbin & Strauss, 2008).

As recommended by Corbin and Strauss (2008), semi-structured interviews were utilized for the grounded theory study to provide a degree of consistency and organization from one interview to the next, and they also allowed the flexibility needed to properly investigate each unique situation. An interview guide was utilized in order to facilitate the face-to-face interviews, observational tour, field notes, and memos (Kvale & Brinkmann, 2009). The interview guide was validated via a field test with an expert panel of two professionals in the technology and engineering education discipline who reviewed it for face and construct validity. The interview guide was revised per the experts' feedback. The interviews were audio recorded and then transcribed verbatim into text files for analysis. The data was analyzed using Glaser and Strauss's (1967) and Glaser's (1978, 2005) classic three-phase grounded theory coding technique and resulted in the emergence of three substantive theories: (a) inefficacious transition to technology and engineering education, (b) value for technical learning, and (c) industry demand-based change (see Table 1).

RESULTS

Of the 379 educators who were sent an email invitation, 96 educators responded, of which 77 met the study requirements and were then categorized by teaching experience, region, and size of school (see Tables 2 and 3). Only two of the 96 respondents were female, and neither was selected through the sampling processes; thus, all participants in the study were males. A final sample size of 13 participants was needed to reach theoretical saturation of the phenomenon. Figure 1 illustrates the approximate location for each of the interviews across the state of Kansas.

TABLE 1: Emergent Theories for Research Questions 1 & 2

Theory	Frequency	%
1. Inefficacious transition to technology and engineering education	13	100%
2. Value for technical learning	13	100%
3. Industry demand-based change	13	100%

NOTE: N = 13.

TABLE 2: Teaching Experience

Experience	Frequency	%
< 9 years	1	7.7
10 - 19 years	1	7.7
20 - 29 years	9	69.2
30 - 39 years	1	7.7
> 40 years	1	7.7

NOTE: N = 13.

TABLE 3: High School Size

Class	Enrollment	Frequency	%
1A	20 - 99 students	2	15.4
2A	100 - 154 students	3	23.0
3A	156 - 249 students	2	15.4
4A	251 - 734 students	2	15.4
5A	737 - 1336 students	2	15.4
6A	1357 - 2258 students	2	15.4

NOTE: N = 13. Enrollment numbers based on 2013-2014 Classifications & Enrollments from the Kansas State High School Activities Association. Retrieved from http://www.kshsaa.org/Public/PDF/Classifications13.pdf

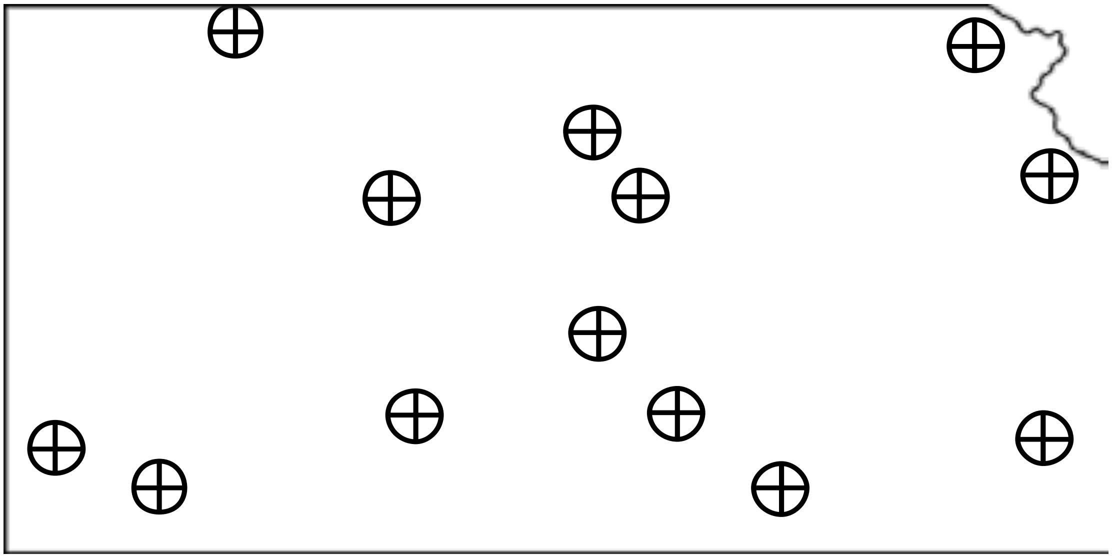

FIGURE 1. Approximate Locations of the 13 Interviews Conducted. Adapted from "Kansas Outline Map" by Graphic Maps, Retrieved June 16, 2014, from http://www.worldatlas.com/webimage/countrys/namerica/usstates/outline/ks.htm. Copyright 2014 by Woolwine-Moen Group. Adapted with permission.

Emergent Theory 1: Inefficacious Transition to Technology and Engineering Education

Though study participants described potential strengths in the technology and engineering education curriculum, their past experience with modular technology and current unfamiliarity with engineering education caused the participants to doubt the efficacy of a technology and engineering education curriculum. All 13 participants (100%) had experience in the transition from industrial arts to technology education through the modular technology initiatives, and none of the participants (0%) continued to teach using this method. The study constructs identified by participants when describing the transition to technology and engineering education included (a) exploratory, (b) short-term, (c) expensive, and (d) unfamiliar (see Table 4).

TABLE 4: Constructs for Technology and Engineering Education

Construct	Frequency	%
1. Exploration	7	54%
2. Short-term	10	77%
3. Expensive	6	46%
4. Unfamiliar	7	54%

NOTE: N = 13.

The participants described the modular initiative through technology education as an effective way to explore a variety of technologies and careers appropriate for students at the junior high level. Participant 8 described the modules as “exciting” where students could explore “electricity, pneumatics, small engines, all kinds of stuff, and it was great fun,” and Participant 6 said, “I think the strengths were that most of the modules kind of interested the students.” As reported by Participant 5, “The strengths were that there were tons of things the kids could do . . . plenty of activities and projects.” However, the participants also noted that the interest and excitement was short-lived, because each modular unit only lasted one or two weeks and shared disappointment in the pedagogy of the modular programs. For example, Participant 11 reflected how the “teacher is not a teacher . . . [but] a facilitator” in a modular-based program. According to Participant 5, the teacher started the students on the first day of the module and then came back on the fifth day to check the students’ work. This type of teaching was labeled “glorified babysitting” by Participant 3; Participants 6, 8, and 13 also identified how the modular program was a challenge for classroom management, and reported problems when students finished early. Participant 13 explained, “There is such a disparity in the amount of work that [it] took to complete them. We had some students who . . . would be done in two or three days, and it’s a 10-day rotation,” while Participant 6 described the same situation when students who “were really top-notch in the class and they would finish that stuff quick. So what do you do with them then? It’s a nightmare.” Participant 8 labeled the overall experience as a “bad time.”

When describing the overall experience of the transition from industrial arts to technology education through the modular programs, the participants described concern in the initial stages and disappointment in the latter stages. Initially, the participants were concerned with schools replacing the traditional shops with the modular classrooms. For example, Participant 1 remembered a nearby school that “basically wiped out their whole woodshop . . . [and] went to all modules,” and Participant 8 reflected, “All around me I was watching all these other schools selling all their shop equipment and go to the mini modules.” Participant 13 shared:

> “I had some big concerns at one point because schools were jumping on the bandwagon of modular and just doing away with shop areas completely. No manual arts, no industrial education whatsoever. Then it seemed like some of those folks who had done away with everything backpedaled a few years later and tried to re-implement the shops again but some of them obviously couldn’t afford it.”

In some schools, the modular programs lasted approximately 10 years, but in other schools they were removed much more quickly. For example, Participant 12 reflected how the modular programs “came in fast and left just as fast as [they] came in.” Overall, the participants shared disappointment for the modular programs and when asked what the phrase technology education meant to Participant 3, the participant simply said, "I think it's a dirty word."

When asked about the potential integration of engineering within the current programs, multiple participants shared concern that it would be too expensive and not fit well with the type of students in their programs. For example, Participant 12 related the engineering expenses to those of the modular programs and didn't believe the school could afford the additional expenses needed to properly incorporate engineering into the curriculum. As for the participation in an engineering-based curriculum, Participant 2 said, "I'm not sure the students have the skill level to do it," and Participant 10 believed it would only be relevant "to a select number of our students." Participant 1 shared that an increase in engineering concepts in the program would discourage the students who need to take the technical courses from doing so because there would be an increase in theoretical concepts and a decrease in hands-on activities.

Two of the participants, both primarily drafting/CAD instructors, were open, receptive, and familiar with current engineering education. Both participants believed they were already incorporating engineering concepts into their programs. Participant 7 emphasized:

> Well I have always been engineering . . . [and] we really haven't changed that much. If we are true to our philosophy then we have been progressing all along with technology because technology is just a facilitator. Engineering hasn't changed it's that technology has been used as a resource to help facilitate engineering.

Participants 5 and 7 articulated that a blend between industrial education, technology education, and engineering education was the best curriculum for students. They described it as a balance between knowledge-based engineering concepts and hands-on technical learning skills.

Emergent Theory 2: Value for Technical Learning

The study participants stressed the importance of teaching technical knowledge and skills through project-based learning. All 13 participants (100%) identified with a strong value in technical learning. The participants described technical learning as broad-based educational experiences that incorporated both the knowledge and skills needed to manipulate resources into useful products. Constructs described by the participants included (a) project-based, (b) skills, (c) hands-on, (d) broad-based, and (e) life-long learning (see Table 5).

The most widely used term throughout the transcripts in relation to technical learning was the root word project (f = 96). All 13 participants (100%) incorporated projects as major components in their curriculum. For example, Participant 6 emphasized the importance for students to "still do projects that they see something from start to finish" and Participant 3 stressed, "these kids have to see something with their hands that they can create on their own, otherwise we lose them. We need to spark interest with what they're good at." The projects implemented into the programs were tangible real-world products designed, created, and kept by the students. For example, Participant 1 contrasted the difference between

TABLE 5: Constructs for Technical Learning

Construct	Word Frequency	Participant Frequency	%
1. Project-based	96	13	100%
2. Skills	69	13	100%
3. Hands-on	65	11	85%
4. Broad-based/exploratory	29	10	80%
5. Life-long	19	8	62%

NOTE: N = 13.

projects created in an industrial education course versus a general education course: ". . . the biggest thing about industrial education is . . . [students] come out with a project at the end that's . . . usable and you actually keep 20 or 30 years down the road," and Participant 12 said:

> We've built a lot of stuff the kids are going to use for the rest of their life. I tell the kids to write down your name, your year, and the school on the bottom or back of your project so when your grandkids are fighting over it, they know when it was built.

Reflecting on the value of the projects, Participant 9 said, ". . . the satisfaction that I see students get here on seeing something built with their own two hands [and] the pride the parents have in the piece of furniture is priceless."

All 13 participants (100%) described the importance of teaching students some degree of technical skills. The root word skill was used 69 times throughout the transcripts. Participant 2 described the importance of applied skills and identified "the problem is that none of the kids know how to build anything and that's where we are really short in our schools. We don't have kids who know how to build stuff . . . they don't have the applied skills." Participant 9 emphasized that the students "have to have the manual skills, those hands-on skills." The participants described a strong connection between skill development and students' being employable in the future. Also related was the role education takes in teaching students skills for a future career.

Eleven out of 13 participants (85%) emphasized the importance of hands-on learning within industrial education. The root word hand was used 65 times throughout the transcripts. Participant 6 identified the purpose of industrial education as a program to "teach students the workings of machines . . . anything that involves working with your hands." Participant 4 described industrial education as "teaching people how to use their hands" and Participant 1 described it as "more hands-on for kids to do something with their hands." Participant 10 was passionate about the hands-on component of the curriculum and exclaimed, "Darn it, we still have kids that . . . love to work with their hands! They love to build something. They love to build things. They are eager to get out and make money, and they can do that." As for a future curriculum, Participant 6 shared concern that "we don't stray too far away from some hands-on skills versus the technology side of things." When discussing labor needs, Participant 5 discussed the need for workers "who know how to use their hands and build things" and Participant 1 described how local companies "can't find enough workers that want to do stuff with their hands and work."

The root word *broad* or *explore* was used 29 times throughout the interview transcripts. Participant 3 identified the broad-based construct as providing the students with a strong technical foundation at the secondary level that could then be mastered in a specific area at the post-secondary level. Participant 7 described broad-based technical learning as teaching students "level 1" knowledge and skills and believed the more refined "level 2" and "level 3" skill sets were more appropriate for the post-secondary level. Participant 9 defined the industrial education curriculum as "exploratory skill building" and described the importance of teaching students a variety of technical experiences that could be transferrable to multiple future career fields. Participant 12 defined the industrial education curriculum as "preparing students with a wide-base knowledge that will give them a step ahead either when they go to a college, a vocational-technical school, or straight out to the working world." Components of the broad-based curriculum described by the participants included the (a) use of tools, (b) use of machines, (c) different materials, (d) safety, (e) use of technology, (f) problem-solving, and (e) design.

The root word *life* was used 19 times throughout the interview transcripts. The life-long learning construct was evident by the participants as they described how the industrial education programs helped students learn future life skills. For example, Participant 8 identified industrial education as a "life learning tool" and Participant 6 described it as developing a "sense of craftsmanship." Participant 8 reflected, ". . . just teaching them something they can use for the rest of their lives just really makes my life." In Participant 12's program the students were expected to demonstrate a strong work ethic and give 100% every day for the whole class. The Participant reflected, "I'd say the one thing that I give my students is pride in what they can do. I think that'll take them a long way in life."

Emergent Theory 3: Industry Demand-based Change

The study participants were most responsive to external change initiatives that were in alignment with changes made in industry, and constructs described by the participants included (a) industry-based technologies, (b) Kansas career pathways, and (c) computer numeric control (CNC) machine (see Table 6). All 13 participants' (100%) programs reflected similarities to traditional industrial education-based programs. For example, Participant 9 described the courses as "pretty traditional project-oriented classes that you would see in most industrial arts programs," and nine of the 13 participants (69%) described how their teaching and curriculum were heavily influenced by the manner of instruction they themselves had in high school or college.

TABLE 6:
Constructs for Industry Demand-Based Change

Construct	Frequency	%
1. Industry-based technologies	9	69%
2. Kansa career pathways	10	77%
3. CNC machine	11	92%

NOTE: N = 13.

Although all of the programs had similarities to traditional industrial education, all 13 participants (100%) described the inclusion, or need for greater inclusion, of current industrial-based technologies within the programs. Nine of the 13 participants (69%) specifically identified making changes based on the current demands of industry. Participant 7 discussed the influence industry should have on the curriculum and stressed how the industrial education courses should "move along with industry" and Participant 5 emphasized, "Industry guides what I do in my classroom. I don't teach these kids something that they won't be able to step into and start running with. Getting [students] ready for industry is my biggest concern." The remaining four participants (31%) who did not specifically identify making changes based on the demands of industry, did however describe the influence of the state's career and technical education pathways initiative on their curriculum. For example, Participants 1 and 6 said, "The state funding pretty much dictates the courses anymore" and "Right now the biggest influence is the state, the funding, and the pathways." When changes did occur, participants reported they were most comfortable with incremental changes. Participant 9 described it as "an evolution at a snail's pace," and Participant 6 agreed and said, "We are slowly changing."

The most common current industrial technology identified by the participants was the inclusion, or the desire to include, a CNC machine. Participant 2 explained, "We incorporate a lot of CNC routing. From very simple stuff [like] inlays and 3D carvings to total projects from start to finish. That's kind of the biggest difference from what we did quite a while ago" as well as Participant 1 who said, "We incorporate a lot more CNC router work." Participants 3 and 9 did not have CNC machines but shared, "I would like to add a little bit more technology like a CNC with our woodworking" and "I would really like to bring in some CNC equipment . . . to add to the expertise of the kids coming out of here and being able to see how the CNC is used in industry." As for the need for more industrial technologies, Participant 7 stressed, "It's absurd that we don't have a CNC. It's absurd that we don't have more advanced technology."

Even though the name of the discipline as a whole had changed twice during the participants' tenure, the name change had little effect on their curriculum as Participant 5 emphasized, "It doesn't really matter what they call it . . . my common goal [is] for putting kids out there that can go to work," and Participant 7 said, "Personally, I don't see it as different. For whatever reason . . . the word industrial or career tech has created [an unacceptable] (connotation) and that my son or daughter is not going into those fields because maybe I'm a white-collar worker." Participant 9 described the changes as "name changes for the sake of trying to define who we are," while Participant 11 rationalized the name change as an "attempt from the state to bring up the quality of students in drafting."

DISCUSSION

The implications of this study may be significant for current practitioners and professional leaders in the technology and engineering education discipline. Though the current study was only conducted within the state of Kansas and the qualitative nature of the study limits the generalizability of the results outside of the study participants, the three emergent theories are significant because they provide evidence of the values and beliefs of the educators in the study and possible constructs for further research. The educators in the study perceived the original transition from industrial arts to technology education as inefficacious and did not see a clear difference in the more recent transition to engineering education. The implication of emergent theory 1 is it provided partial explanation as to why industrial education teachers have resisted the curricular transition to technology and engineering education (i.e., research question 2). Just as industrial educators resisted the initial transition from industrial arts to technology education (Kelley & Wicklein, 2009; Rogers, 1992), the emergent theory indicated educators would continue to resist the latter changes toward engineering design unless there is a clear demonstration on the efficacy of the curriculum and changes are made in alignment with emergent theories 2 and 3.

Emergent theory 2 clarified a distinction between the educational philosophies of technology and engineering education leaders and practitioners in the field in that the leaders of the discipline have built and promoted a curriculum through a theoretical lens based on a liberal education for all students, whereas industrial educators have adopted a more blended approach between general education and vocational education with an emphasis in technical learning. This differentiation provides a partial explanation for the discipline's identity crisis documented over the past three decades (Akmal, Oaks, & Barker, 2002; Katsioloudis & Moye, 2012; Sanders, 1997) and insight into the cultural values of industrial education teachers.

Industrial educators made incremental changes in alignment with industry-based career and technical education initiatives. The implication of emergent theory 3 is that it identified the partial existence of the educational philosophy of vocationalism with industrial education teachers in Kansas. As part of the 21st century dialogue on college and career readiness through the transition from vocational education to career and technical education, the Kansas State Department of Education established multiple incentives for high schools to emphasize career readiness, including additional school funding and tuition-free postsecondary credits for students enrolled in career and technical education courses.

Another implication of emergent theory 3 for the technology and engineering education discipline was it identified a greater alignment among industrial education teachers with vocational-oriented programs through career and technical education and not with broad-based technology literacy programs through technology and engineering education. In aligning their programs with the current demands and needs of industry, industrial educators demonstrated they were not outright resistant to change, but instead demonstrated an ideological and cultural resistance to the technology and engineering education curriculum as inquired by research question 1. The educators did not perceive the recommended broad-based technology and engineering education curriculum as relevant to the industrial career paths of students and therefore resisted the transition and instead made changes associated with the career pathway initiatives that align with industry-based demands and statewide initiatives (Moye et al., 2012; Wright et al., 2008).

CONCLUSION

The three emergent theories may provide useful information for the leaders of technology and engineering education in addressing the division and identity crisis within the discipline (Akmal et al., 2002; Katsioloudis & Moye, 2012; Sanders, 1997). The evidence from the emergent theories indicates that the leaders of the technology and engineering discipline need to evaluate the current technology and engineering education curriculum and (a) differentiate it from the previously recommended modular technology units, (b) identify opportunities for technical learning, and (c) identify alignments between the learning activities and the demands of industry. This current study was only conducted within the state of Kansas and the qualitative nature of the study limits the generalizability of the results outside of the study participants. Therefore, future research is needed to operationalize the emergent theories, test the theories, and survey a larger geographic population to generalize the findings to a larger population of educators.

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An Investigation of Measurement Uncertainty of Coordinate Measuring Machines (CMMs) by Comparative Analysis

By Jayson Minix, Hans Chapman, Nilesh Joshi, and Ahmad Zargari

ABSTRACT

Measurement uncertainty is one of the root causes of waste due to variation in industrial manufacturing. This article establishes the impact of certain factors on measurement uncertainty while using coordinate measurement machines as well as its reduction through the usage of recognized Gage R&R methodology to include ANOVA. Measurement uncertainty stemming from equipment and appraiser variation is identified and ranked according to its degree of impact. A comparative analysis is conducted showing how different CMMs of similar design can generate differing amounts of measurement uncertainty. The approach set forth in this paper not only proves effective with CMMs but can also be applied to other complex multivariate measurement systems.

Keywords: coordinate measuring machine, gage repeatability & reproducibility, equipment variation, appraiser variation, measurement system analysis, measurement uncertainty.

INTRODUCTION AND STATE OF THE ART

Measurement error is one of the root causes of variation, or waste, in any manufacturing process. As such all measurement errors must be properly identified and understood in order to determine the quality of a manufacturing process. This task is accomplished by performing a Measurement System Analysis (MSA) on each measurement system in a given manufacturing process. Perhaps the most well known type of MSA performed is a Gage Repeatability & Reproducibility (R&R) Study.

Gage Repeatability is primarily the variation observed in the measurement gage itself and is often considered to be the equipment variation. Gage Reproducibility is variation introduced into the measurement system when a variable is changed, that is, a different operator using the same gage. The repeatability and reproducibility combined are what determines the total "measurement error," or "noise" in a given measurement system. This noise is the source of measurement uncertainty in the measurement data (Kappele, 2005).

Typically a measurement system is considered capable if it has a low amount of uncertainty. Ideally this is determined by less than 1% noise and a total Gage R&R of less than 10%. The total percentage of Gage R&R is a combination of both the measurement uncertainty as well as part-to-part variation. Systems having more than 10% noise or a combined Gage R&R of more than 30% are considered unacceptable, and every effort should be made to improve the measurement system (MSA Workgroup, 2010).

The three most recognized methods of Gage R&R as set forth in the Measurement Systems Analysis Reference Manual are the Range Method, the Average & Range Method, and the Analysis of Variance (ANOVA) Method. The Measurement Systems Analysis Reference Manual is a publication put together by the Automotive Industry Action Group (AIAG) and serves as a reference for Gage R&R methodology that has been sanctioned by the Chrysler Group LLC, Ford Motor Company, and General Motors Corporation Supplier Quality Requirements Task Force (MSA Workgroup, 2010).

Coordinate measuring machines are a common measurement device used to secure measurements of high accuracy across various industries. They range in type from table-top bridge-type machines with touch type probes to much more advanced technology using hand-held devices and optical laser type probes. Rather than technically measuring component parts in the traditional sense, CMMs obtain discrete points or hits on a three-dimensional Cartesian plane and generate measurement data through algorithmic mathematical computation.

A number of researchers have made significant progress toward developing methodologies aimed at estimating measurement uncertainty that results in coordinate measurements, particularly using contact-mode probes. Yet, considerable research remains to be performed to fully account for measurement uncertainty and to improve their estimation. For example, techniques to model and estimate task specific uncertainty for contact-probe coordinate measuring machines were developed by Wilhelm et al., (2001), who reported that for any task specific uncertainty method to gain universal acceptance, standardized inputs would be highly desirable, if not a requirement. In their investigation of measurement uncertainty estimation of CMMs in accordance with the Guide to the Expression of Uncertainty in Measurement (GUM), Fang and Sung (2005) noted that measurement uncertainties mainly come from the calibration of the CMM and temperature. For a measurement range of 0 mm to 400 mm, they estimated an expanded uncertainty of 3.4 µm with a coverage factor of 1.98 at a 95% confidence interval. Their further analysis showed that the measurement uncertainty can be reduced by using a high precision instrument, such as laser interferometer.

The principal factors that impact measurement uncertainty have been studied extensively. Barini et al. (2010) investigated the source and effects of differing uncertainty contributors by point-by-point sampling of complex surface measurements using tactile CMMs. By carrying out a four-factor (machine, probe, operator, and procedure), two-level randomized factorial experiment and choosing adequate process parameter settings, a subsequent decrease of the measurement uncertainty from 34 µm to 8 µm was observed.

Other researchers have used other approaches. In their work, Phillips et al. (2010) utilized a computer simulation software approach to investigate the validation of CMM measurement uncertainty. All the measurement errors found in the physical measurements were well inside their corresponding uncertainty intervals. From their investigation, Phillips et al. suggested a well-documented list of reference value tests as a useful tool to employ before starting the more expensive aspect of real physical measurements of calibrated parts.

Case Study Background

Data for this study was collected using two separate CMMs; the first is located in the CMM Laboratory of the School of Engineering and Information Systems, Morehead State University and the second from a CMM Lab located in a Tier 1 Original Equipment Manufacturer (OEM) facility. Both machines were similar in design, utilizing a bridge type table design with Direct Computer Control (DCC) capability. The primary differences of the two machines were that they are manufactured by different companies and each functions with a different operating software. The machine used in the university laboratory was manufactured by Brown & Sharpe and is operated by PC•DMIS 2014 software; while the second machine was manufactured by the Zeiss company and operated by Calypso 4.8 software.

As many controls as possible were maintained during the study to ensure a quality comparative analysis between the two machines. For example, the same participants were used to collect measurement data on each of the CMMs. Additionally, all data were collected by measuring the same three sample parts with each machine. The DCC mode was utilized on each machine in lieu of a third operator to provide baseline data.

METHODOLOGY

The overall methodology of this research is based on the American Automotive Industry standard requirement for Gauge R&R studies. One of the challenges faced by quality professionals who supply products to customers in the American Automotive Industry (AAI) is not only complying with an extensive list of customer specific requirements, but also complying with those requirements in the specific manner prescribed by the customer as well. An especially good example of this challenge is encountered when attempting to comply with customer requirements pertaining to MSAs and the documentation of the measurement variation present with each gage used to release product to the customer.

While the core tools reference manuals contain good practices and methods this is not the same as being “best” method across the board in every instance. As the name implies these manuals were originally created as “reference” guides, but over the years the AAI requirements have evolved to the point that these guides have changed from references to requirements for the entire automotive supply chain. This phenomenon in and of itself poses its own set of unique obstacles and challenges to those in the field of quality due to the fact that "not all measurements systems are created alike." The result is a tendency to analyze a measurement system through the lens of the required method for the purpose of compliance to the requirement, rather than analyzing a measurement system with the intent of truly understanding the capability and uncertainty of the system itself.

Rationale of the Four Factors Selected for Analysis

Dimensional type:

The three separate dimensional measurement types selected are referred to in the CMM operator's manual as 'geometric features'. They were selected due to the way a CMM generates three-dimensional measurements differently than two-dimensional measurements. When three-dimensional objects are measured, probe radius compensation is made perpendicular to the surface of the object as opposed to the active work plane used in two- dimensional objects.

Operation type:

The decision between a manually operated CMM versus a DCC type is typically determined by the type of operation in a given organization. Most production-oriented environments choose a DCC type, while companies specializing in prototype development and reverse engineering are more likely to prefer a manual CMM (Meredith, 1999). However this does not mean to imply that a CMM with DCC capability is always being utilized in DCC mode. DCC CMMs can still be operated in manual mode.

Set-up type:

The two different CMM setup types that are under investigation are those of manual setup and CAD setup. Both setup types are directly linked to a DCC operation type. The integration of advanced CAD inspection programs has provided yet another layer of part inspection versatility to the realm of metrology. Through the usage of CAD enhanced CMM software, it is now possible to graphically test and debug inspection routines before executing a new part program with the CMM (PC•DMIS, 2014).

Operator:

With nearly all types of measurement system analysis, the operator(s) involved tend to contribute significantly towards the overall measurement variation in the system.

Method One – Analysis of Variance ANOVA

An Analysis of Variance (ANOVA) was performed to determine the significance of impact of the four selected factors on overall measurement uncertainty associated with a CMM. This test was conducted with a 95% confidence level. When a statistical significance was discovered while comparing a set of three or more means, a post hoc Tukey Test was performed to determine which means were significantly different.

Method Two – Gage Repeatability & Reproducibility

A series of Gage R&R studies were performed using the equations and methodology set forth by the MSA Reference Manual. The results of the Gage R&R studies determine the percentages of variance that each of the four categorical factors contribute towards the overall measurement uncertainty in this particular study. These equations are as follows

Equation 1:

$$EV = \overline{\overline{R}} \cdot K_1$$

K_1 = a compensation constant based on the number of trials used.

Equation 1 was used to calculate Repeatability / Equipment Variation (EV)

Equation 2:

$$EV = \sqrt{(X_{diff} \cdot K_2)^2 - \frac{EV^2}{n - r}}$$

K_2 is a compensation constant based on the number of appraisers used.

n = parts r = trials

X_{diff} is the difference between the greatest and least X_{bar} of all trials and all parts for each appraiser

Equation 2 was used to calculate Reproducibility / Appraiser Variation (AV).

Equation 3:

$$GRR - \sqrt{EV^2 + AV^2}$$

Equation 3 was used to calculate GRR (combined Gage R & R).

Equation 4:

$$PV = R_p \cdot K_3$$

K_3 is a compensation constant based on the number of parts used

R_p is the range of part averages

Equation 4 was used to calculate the PV (Part Variation).

Equation 5:

$$TV = \sqrt{GRR^2 + PV^2}$$

Equation {5} was used to calculate TV (Total Variation)

The following equations were used to calculate the percentages of AV, EV, & GRR. (The percentage of PV is of no consequence in this research since the part to part variation is not under investigation.)

Equation 6:

$$\%AV = 100 \cdot \frac{PV}{TV}$$

Equation 7:

$$\%AV = 100 \cdot \frac{PV}{TV}$$

Equation 8:

$$\%GRR = 100 \cdot \frac{GRR}{TV}$$

Method Three – Comparative Analysis

A statistical comparative analysis was performed using data collected from two separate CMMs.

Data Collection Procedures:

Data was collected at the university lab over the course of several days. The same participants were involved throughout the entire data collection process. The temperature in the lab was carefully monitored and measurements were only taken when the lab temperature was maintained within 20°C +/- 2°C in accordance to the universally accepted standards established by the NIST (Doiron, 2007).

The Gage R&R data were collected while operating the CMMs in different configurations. While collecting data using the CAD capability, the software was completely closed out and reopened in identical sequence for each iteration.

While measuring the conic sections, it was necessary to calculate angular measurements due to the limited capabilities of one of the CMMs.

Equation 9 was used to convert from linear into angular for the outer base angle of the cone.

Equation 9:

$$\tan\theta = \frac{Height}{\frac{Diameter_2 - Diameter_1}{2}}$$

θ represents the outer base angle of the Cone.

$Diameter_1$ & $Diameter_2$ are the diameters of the upper and lower planes of the conic section.

Since all raw data were in the form of different units of measure it was first necessary to normalize data before performing an ANOVA. Data were normalized according to each distinct dimension type. Data normalization was performed using Equation 10.

Equation 10:

$$X_n = \frac{X_t - X_{min}}{X_{max} - X_{min}}$$

RESULTS

After analyzing the data, the following findings were discovered, and the four factors being analyzed were then ranked according to their impact on the overall MSA.

The impact of each selected factor on the measurement system variation

Residuals plots were analyzed in connection with each factor (Figures 1-3) each of which demonstrate no indication of bias in any of the ANOVAs. The histogram and normality plots show no skew or outliers, and the residuals appear normally distributed. The Residuals vs. Fits graphs all indicate that the residuals have a constant variance and the Residuals vs. Order plots show no apparent correlations between any of the data.

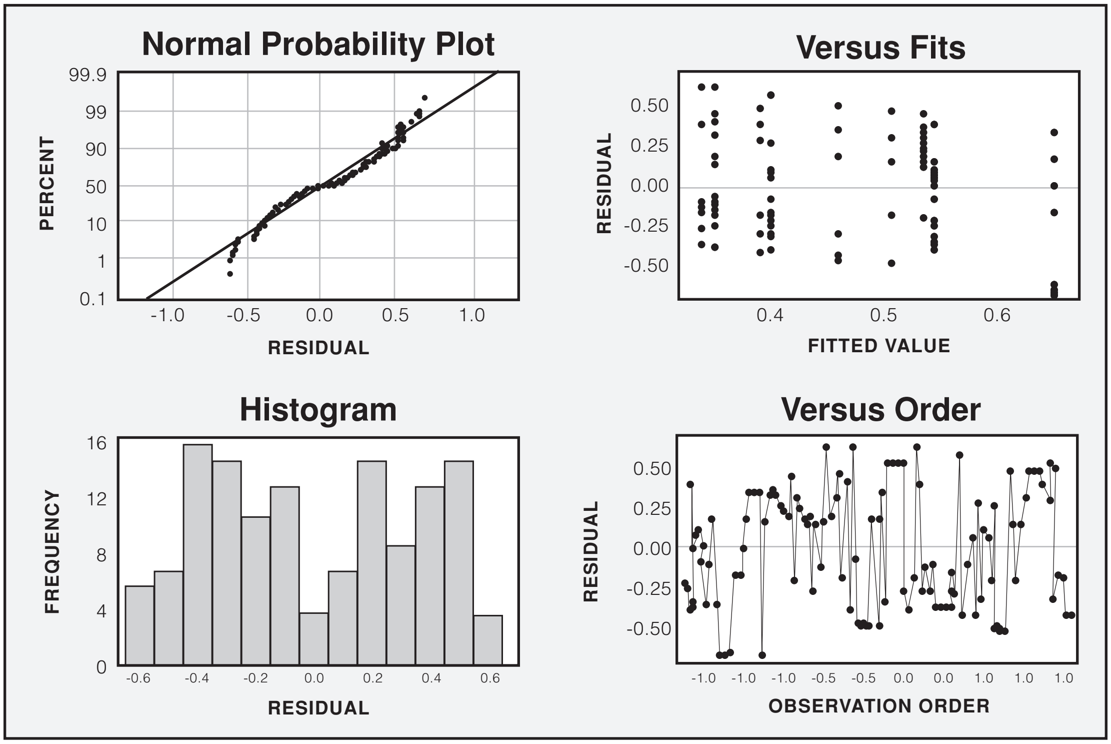

FIGURE 1. Four in One Residuals Plot for Measurement Type

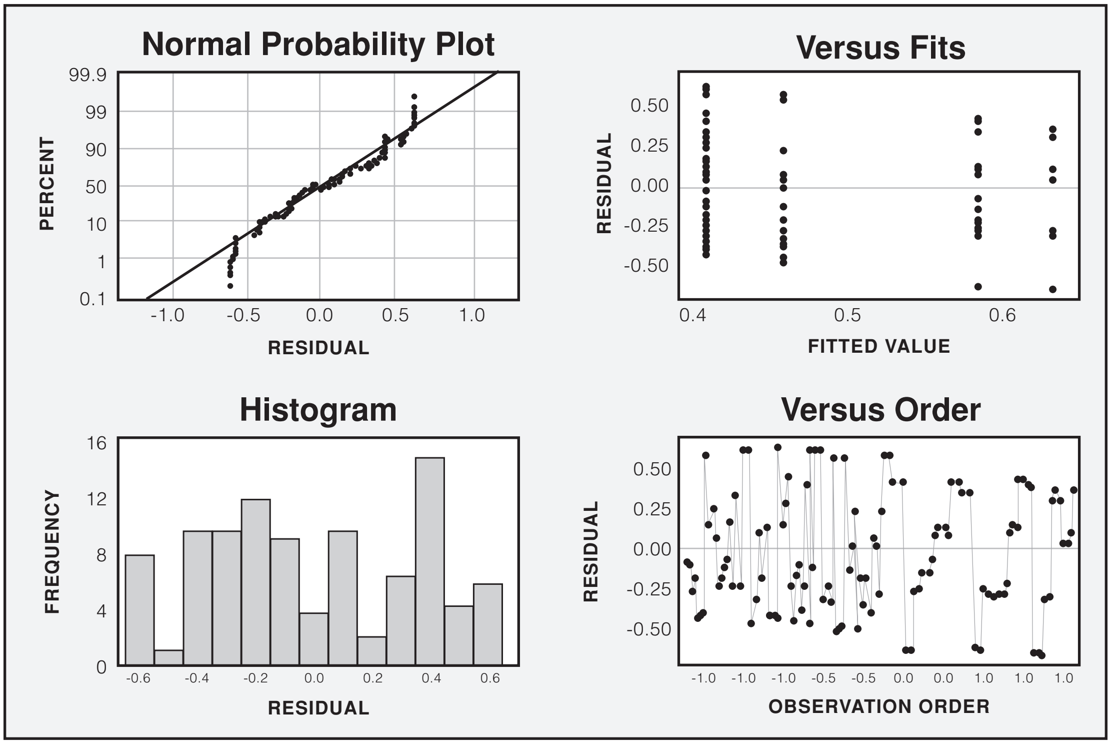

FIGURE 2. Four in One Residuals Plot for Operation Type

In addition to each ANOVA, a Tukey Pairwise Comparison of Means test, also known as Tukey's Honestly Significant Difference test, was conducted when P values of the ANOVA were discovered below the risk value. A Tukey Test was used to reveal which means in a given data set differed significantly from the rest (Olleveant, 1999).

Result 1a - Measurement Type.

An analysis of the variation related to 3D measurement type when operating the CMM in manual mode revealed a notable amount of both EV and AV variation when compared to the variation encountered from the other factors. The cylinder consistently yielded the highest amount

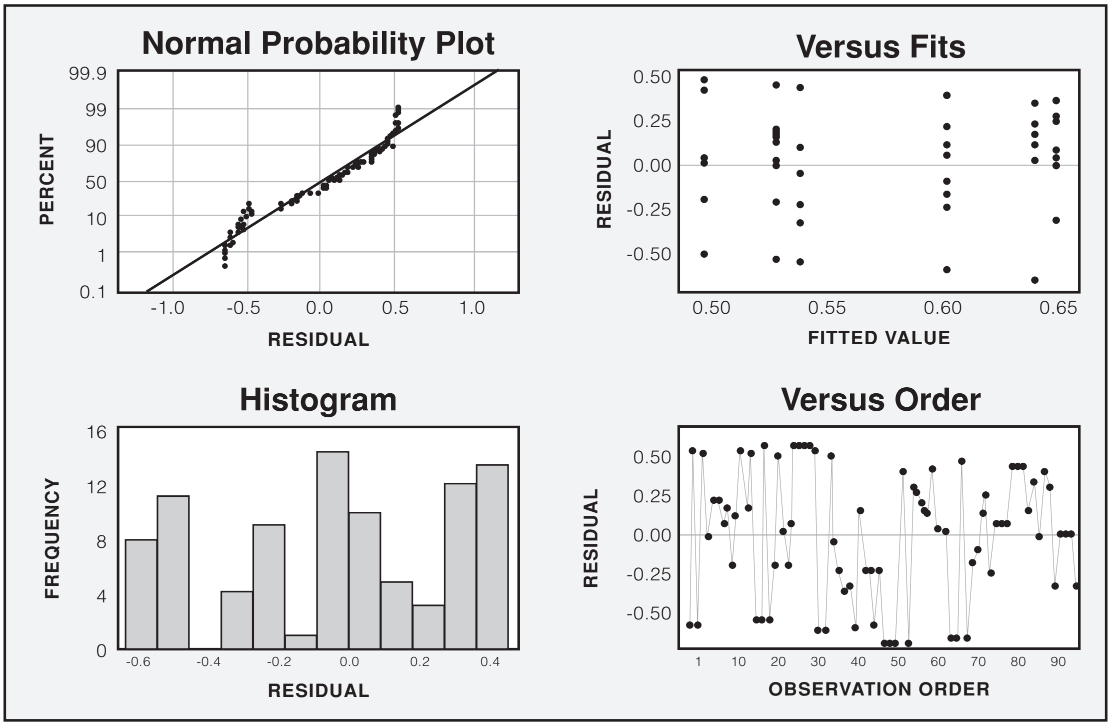

FIGURE 3. Four in One Residuals Plot for Setup Type

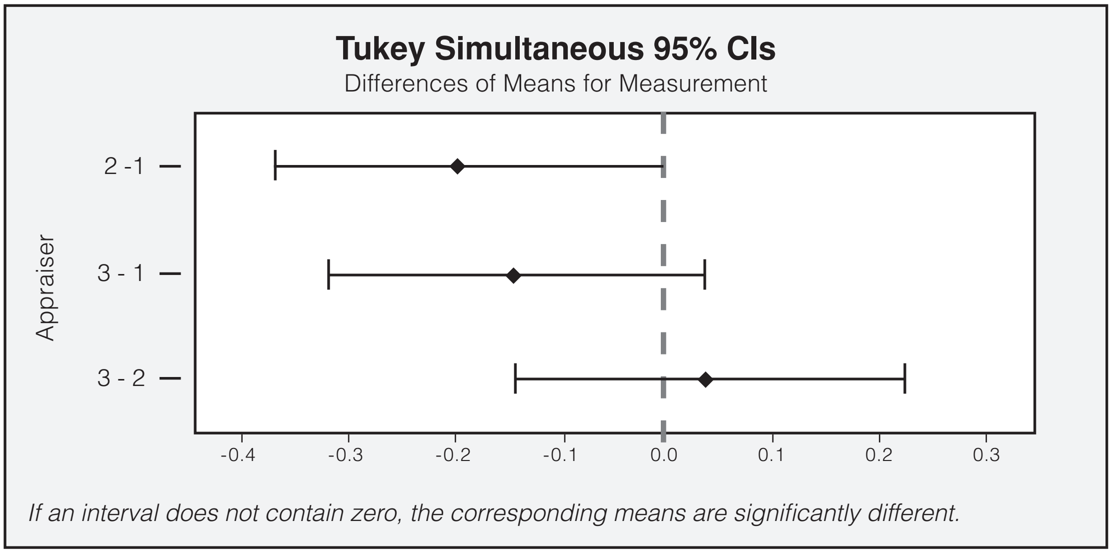

FIGURE 4. Tukey Test of Appraisers for Measurement Type

of both EV and AV variation. The cone ranked second with the sphere displaying the least amount of variation.

The first ANOVA was conducted on data relating to 3D measurement type. Because the P-value for the appraisers was determined to be below the alpha value of 0.05 (although only slightly at 0.048. (Table 1, on page 60), it was determined that the difference in means between the appraisers in this particular study was statistically significant. All data was first analyzed and found to be normally distributed.

Figure 4 shows that the data collected by Appraisers 1 and 2 were significantly different from each other while measuring the different three dimensional shapes.

Result 1b – Machine Operation Type

The second factor investigated was Machine Operation Type. The Gage R & R data reveals the presence of both EV and AV variation while

TABLE 1: ANOVA of Measurement Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Appraiser	2	0.8262	0.8262	0.4131	3.12	0.048
Dimension Type	2	0.3626	0..3626	0.1813	1.37	0.258
Error	130	17.2324	17.2324	0.1326		
Total	**134**	**18.4212**				

TABLE 2: ANOVA of Operation Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Appraiser	2	0.1006	0.1006	0.0503	0.38	0.682
Dimension Type	1	1.4624	1.4624	1.4624	11.17	0.001
Error	176	23.0415	23.0415	0.1309		
Total	**179**	**24.6045**				

TABLE 3: ANOVA of Setup Type

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Appraiser	2	0.0339	0.0339	0.0169	0.12	0.887
Dimension Type	1	0.2576	0.2576	0.2576	1.83	0.18
Error	86	12.1049	12.1049	0.1408		
Total	**89**	**12.3964**				

in Manual Mode but not while in DCC mode. This finding was also supported by the ANOVA which demonstrated statistical significance for the variation between the two modes of operation as shown in Table 2.

Result 1c – Machine Set-up Type

The third factor, Set-up Type, proved to be the least significant of each of the four factors analyzed. Very little if any variation was observed in both AV and EV for either set-up type. This produced a negligible GRR% overall. These results were supported by the ANOVA, as seen in Table 3. The data reveal no presence of measurement noise when utilizing CAD capable software in both DCC and manual modes.

Result 1d – Operator

The fourth factor investigated was variation attributable to machine operators. In order to determine the impact of this variation it was first necessary to examine the AV in connection with each of the other independent factors. As the data in Table 4 shows, Appraiser Variation is present in some configurations but not in all. As seen in Table 4, the two configurations with the least amount of appraiser variation were a) when measuring spherical objects, and b) when operating the CMM in DCC mode.

TABLE 4: Summary of Gage R&R Results

Factor	*EV µ*	*% EV*	*AV µ*	*% AV*	*GRR µ*	*% GRR*
1a) 3D Measurement / Sphere	0.015	0.21%	0.002	0.03%	0.015	0.21%
1b) 3D Measurement / Cylinder	0.195	1.11%	0.131	0.75%	0.235	1.34%
1c) 3D Measurement / Cone	0.058	0.50%	0.064	0.55%	0.086	0.74%
2a) Operation Type / Manual	0.105	0.83%	0.067	0.53%	0.124	0.99%
2b) Operation Type / DCC	0.000	0.00%	0.004	0.04%	0.004	0.04%
3a) Setup Type / Manual	0.006	0.21%	0.006	0.22%	0.009	0.31%
3b) Setup Type / CAD	0.005	0.16%	0.004	0.14%	0.006	0.21%

TABLE 5: Ranking of Individual Factors

Factors by Ranking	*Combined Average of Individual Factors*
1) Measurement Type	(0.15 + 0.195 + 0.058) ÷ 3 = 0.134
2) Operation Type	(0.105 + 0.00) ÷ 2 = 0.0525
3) Operator	(0.002 + 0.131 + 0.064 + 0.067 + 0.004 + 0.006 + 0.004) ÷ 7 = 0.040
4) Setup Type	(0.006 + 0.005) ÷ 2 = 0.006

Factors Ranked by Impact

Result 2 – Ranking the factors

After extracting the EV for each factor using the series of Gage R&R methodology, the grand mean of each individual component of EV was calculated. This data was then sorted in Table 5 providing a ranking of the impact of each individual factor on the overall measurement uncertainty of the system.

Comparative analysis of the two separate CMMs

Figures 5 and 6 are images taken of both individual CMMs used for the comparative analysis. The individual parts measured in the study can also be seen clearly on the table surface of the CMM in Figure 5.

FIGURE 5. Image of CMM Located in University Laboratory

FIGURE 6. Image of CMM Located in Tier 1 Industry Laboratory

TABLE 6: Case Study Gage R & R Summary

Different CMMs	EV µ	% EV	AV µ	% AV	GRR µ	% GRR
1) Machine 1- MSU Laboratory	0.150	0.51%	0.096	0.33%	0.178	0.61%
2) Machine 2 - Industry Laboratory	0.094	0.32%	0.066	0.23%	0.115	0.39%

TABLE 7: Case Study Statistical Summary

Statistic	Tier 1 OEM CMM	University CMM
1) Mean Standard Deviation	0.104 µ	0.360 µ
2) Mean Range	0.386 µ	1.036 µ

For the purpose of conducting the comparative analysis, a few individual components were selected and then firmly secured to the table top surface of each CMM prior to securing measurements. The statistical data for comparative analysis are displayed in Tables 6 and 7 below.

Tables 6 and 7 clearly demonstrate differing amounts of EV and AV data are present when identical parts are measured by the same operators on different CMMs of similar design. Additionally, both the GRR results as well as the statistical summary indicate a greater presence of measurement variation when using the CMM located in the university lab.

CONCLUSION

This study has revealed the presence of varying degrees of measurement uncertainty while operating CMMs in different configurations. The extent of impact of this uncertainty for CMMs must be determined by the associated user. It is noteworthy that this work revealed that differing amounts of equipment variation (EV) and appraiser variation (AV) are present when identical parts are measured by the same operators on different CMMs of similar design.

The impact of each of the four individual factors on the overall measurement uncertainty was revealed in rank order from highest to lowest as: Measurement Type, Operator Type, Operator, and Set-up Type. Furthermore, a Comparative Analysis between the industry CMM and university CMM, based on both the Gage RR and ANOVA results, indicated a greater presence of measurement variation when using the university CMM.

While the methodology set forth in this study may not necessarily encompass all cases, it has proven effective to adequately perform an MSA on a CMM. The same result could be expected for future studies of similar complex multivariate measurement devices.

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Flexible and Job-Embedded Professional Development for In-Service Technology, Design, and Engineering Educators

By Jeremy V. Ernst, Aaron C. Clark, and Sharon W. Bowers

ABSTRACT

Technology, design, and engineering (TDE) eduction teachers have less access to quality professional development than other Science, Technology, and Mathematics (STEM) educators.

To address this need, the *Transforming Teaching through Implementing Inquiry* (T2I2) project created an online professional development system for TDE secondary educators. The online professional learning experiences, defined by National Board for Professional Teaching Standards (NBPTS), reinforce and introduce instructional practices that promote student learning. For this study, two groups of teachers, selected from five states (Illinois, Kentucky, Ohio, North Carolina, and Virginia), completed the T2I2 curricular units and submitted artifacts/evidence of practice. Analysis of the artifacts, using the non-parametric Wilcoxon-signed-ranks Test, provides evidence that the teachers within the pilot studies demonstrated proficient abilities to manage, monitor, and adjust learning environments; contribute to a learning community; and increase their self-assessment following the completion of the curriculum. These results led the authors to suggest further use of the learning platform with in-service teachers in related STEM disciplines that face comparable pedagogical challenges.

INTRODUCTION

The importance of quality teacher learning opportunities cannot be overstated. Teacher quality is consistently noted as a critical factor that impacts student learning (National Research Council [NRC], 2010). Effective professional development that affects teacher quality requires flexible, job-embedded, results-driven learning experiences, which are focused on content that integrates directly into classrooms and builds a community of learners (Ernst, Segedin, Clark, & DeLuca, 2014; Garet, Porter, Desimone, Birman, & Yoon, 2001; National Staff Development Council [NSDC], 2001; Schlang, 2006; Weiss & Pasley, 2006). Changes in teacher practice require time, with some states mandating as many as 19 professional development days annually (Ernst, Clark, DeLuca, & Bottomley, 2013; Jacob & McGovern, 2015). Such time is well spent when this work results in improving teaching skills and pedagogical content knowledge (Li, Ernst, & Williams, 2015).

National STEM education initiatives (Science, Technology, Engineering, and Mathematics) education initiatives call for high quality professional development for STEM educators; however, professional learning experiences for technology, design and engineering (TDE) educators pale in comparison to professional development for other STEM disciplines. Often these are characterized as less comprehensive and perceived to have little value (DuBois, Farmer, Gomez, Messner, & Silva, 2009; Li, Ernst, & Williams, 2015; NRC, 2009). Professional development for these TDE educators is often found to be inadequate and limited (National Academy of Engineering, 2009).

The lack of technology education National Board for Professional Teaching (NBPT) certified teachers, and an increasing shortage of TDE educators further accentuates the need for quality professional development and an enhanced pipeline for this group of educators (NBPT, personal communication, October 2012). To address the shortage, thirty-nine states (78%) utilize alternative routes, such as career-switcher programs, to licensing TDE educators (Ndahi & Ritz, 2003). Targeted professional learning experiences and supported networks are needed to sustain and build teacher practices of newly qualified teachers.

This demonstrated need for professional development that focuses on improving TDE educators' teaching skills and pedagogical content knowledge was the impetus behind the development and implementation of the *Transforming Teaching through Implementing Inquiry* (T2I2) project. T2I2 is an online professional development system for grades 6-12 TDE educators. The system content targets implementation and instructional practice, as defined by NBPTS, in support of quality classroom indicators for the promotion of student learning. T2I2 professional development is research-informed, interactive, and object-oriented, built upon professional learning frameworks developed and refined within prior studies such as Visualization in Technology Education (VisTE) and the Tech-Know Project (Ernst & Clark, 2007; Ernst, Taylor, & Peterson, 2005). These frameworks utilize state-of-the-art course content management and collaboration software to provide clear, challenging, connected, and coherent professional learning experiences for educators that encourage critical reflection on practice and self-evaluation through "sustained opportunities over a substantial time interval" (Mundry, 2007; NRC, 2011). Utilizing this web-based platform, T2I2 was designed to introduce, reinforce, and develop TDE educators' abilities in regard to the art and practice of teaching.

Research Hypotheses

This study's five investigational hypotheses address teachers in the pilot groups' abilities to manage, monitor, and adjust their learning environments; to develop reflective self-assessment strategies; and to increase contributions to the broader learning community.

> **Research Hypothesis 1:** A teacher's ability to manage learning environments was deemed proficient following the use of the T2I2 professional development materials.
>
> **Research Hypothesis 2:** A teacher's ability to monitor learning environments was deemed proficient following the use of the T2I2 professional development materials.
>
> **Research Hypothesis 3:** A teacher's ability to adjust learning environments was deemed proficient following the use of the T2I2 professional development materials.
>
> **Research Hypothesis 4:** A teacher's ability to contribute to the learning community was deemed proficient following the use of the T2I2 professional development materials.
>
> **Research Hypothesis 5:** A teacher's ability to increase self-assessment was deemed proficient following the use of the T2I2 professional development materials.

The teachers' skills and abilities were documented through written and video artifacts, similar in design to artifacts developed for NBPT certification.

STUDY PARTICIPANTS AND METHODOLOGY

For the first year of the two-year pilot study (2012-2013), 190 applicants applied to participate from a five-state (Illinois, Kentucky, Ohio, North Carolina, and Virginia) list-serve recruitment. All candidates were middle or high school teachers identified as not holding Technology Education NBPT certification. From the applicant pool, eight middle school and eight high school teachers were randomly selected to participate in the first year of the pilot study. For the purposes of this research, these sixteen teachers agreed to: (a) complete 17 Learning Objects within the T2I2 curriculum and (b) submit artifacts/evidence of practice, upon the completion of this work. The 17 Learning Objects are clustered into the following four units: Demonstration Lesson, Fostering Teamwork, Assessment of Student Learning, and Documented Accomplishments. These units were based upon NBPTS' expectations. Learning Objects are modular lessons that contain materials and information created by a team of TDE NBPT-certified teachers, TDE teacher educators, and in-service veteran TDE K-12 educators. Learning Objects provide a research-informed basis for each topic through the "Impact on Learning" sections, a step-by-step implementation approach through the "Procedures in the Classroom" sections, and specific methods to identify if the process has been successfully implemented through the "Determine Success" sections. As teachers finish each Learning Object they complete a five-question post assessment quiz to check for understanding. Upon the completion of all Learning Objects within a unit, pilot teachers submitted written and/or video artifacts as evidence to document their abilities to implement newly learned practices. The post-assessment quizzes offered formative assessment to the research team. The assessment of the artifacts addressed the research hypotheses.

Teachers for the second year of the pilot study (2013 - 2014) were, once again, selected from the five project states. An additional sixteen pilot study teachers, eight middle school and eight high school, were randomly selected from 141 applicants. Teachers within this second pilot group agreed to complete the same tasks identified for the original group. For both pilot groups, teachers were introduced to the T2I2 website, resources, and project expectations through an introductory webinar run in early September of each academic year. Following the webinar, teachers were offered support from the T2I2 team through monthly email contacts and Skype office hours. Work for each pilot group was targeted to be completed by March of each year.

Quantitative research methods were employed to form the basis of this research using data from both pilot groups. Data collected includes the mean for each Learning Object's post-assessment and average number of attempts. Data addressing the five research hypotheses was derived from teacher artifacts, four written commentaries and two video commentaries, scored by an NBPT-certified teacher using an adapted rubric and four-point scoring system. Researchers used non-parametric statistical analysis to determine a teacher's ability to manage, monitor, and adjust the learning environment in his/her classroom; contribute to a learning community; and increase self-assessment.

This study was initially proposed as a treatment and control study. However, after negotiation with the sponsoring entity, it was determined that the project would be better poised to increase the treatment group to broaden impact. Based upon this guidance, a directional study was planned to examine teacher proficiency.

Instrumentation

The pilot teacher outcome data, in the form of teacher artifacts, were measured by NBPTS criterion-referenced metrics, targeting the teachers' abilities to manage, monitor, and adjust a learning environment to improve instruction; conduct self- assessment; and contribute to a learning community. The criterion-referenced metrics were organized around four entries where project Learning Object alignment has been achieved. The Learning Objects, grouped into units, are lessons that introduce and apply specific content, practices and pedagogy for participating teachers. A unit is a logical grouping of several individual Learning Objects. The pilot teachers were expected to complete all units, but, within the T2I2 system, the units do not have to be completed sequentially.

The scoring instances (n) varied depending upon the teacher artifacts submitted and determined to be complete by the project evaluation team. The research hypotheses, related units and Learning Objects, and NBPTS artifacts are found in Table 1. The first and fourth research hypotheses are addressed through evidence acquired from the written commentary and video artifacts submitted following completion of Learning Objects within the Demonstration Lesson unit. These Learning Objects introduce the following topics: Designing Standards-Based STEM, Lab and Class Management, and STEM Curricula. The second research hypothesis is addressed through evidence found within the written commentary and video artifacts following completion of the Fostering Teamwork unit that includes Learning Objects that introduce: Best Practices; Classroom Quality, Enhancing Classroom Creativity, Implementing Learning Activities Multiculturalism in the Classroom, and Working with Special Populations. Research hypothesis three is addressed following the teachers' submission of the written commentary after completing the Assessment of Student Learning unit that contains Learning Objects focusing on Action Research, Adapting Instruction, Data Analysis, Formative Evaluation Techniques, and Initial Student Evaluation. The final research hypothesis was addressed by analyzing evidence submitted by teachers in the form of a description and analysis, following the teachers' completion of the Documented Accomplishments unit that contains the Professional Organizations, School and Community, and Student Organizations Learning Objects.

An NBPT-certified assessor reviewed all of the submitted artifacts using an adapted four-point rubric ranging from (4) performance provides clear, consistent, and convincing evidence to (1) performance provides little or no evidence. The NBPTS metrics identifies teacher proficiency as (3) performance provides clear evidence. Teachers were provided written feedback from this review. Proficiency (3) was the level of performance identified within each directional research hypothesis.

TABLE 1: T2I2 teacher artifacts aligned with hypotheses, units, and learning objects

Hypotheses	*Unit and Learning Objects*	*NBPTS Artifacts*
Research Hypothesis 1: H0 - A teacher's ability to manage learning environments was deemed proficient following the use of the T2I2 professional development materials.	**Demonstration Lesson:** Designing Standards Based STEM; Lab and Class Management; STEM Curricula	Entry 2.1: Video Capture
Research Hypothesis 2: H0 - A teacher's ability to monitor learning environments was deemed proficient following the use of the T2I2 professional development materials.	**Fostering Teamwork:** Best Practices; Classroom Quality; Enhancing Classroom Creativity; Implementing Learning Activities; Multiculturalism in the Classroom; Working with Special Populations	Entry 3.1: Video Capture Entry 3.3: Written Commentary
Research Hypothesis 3: H0 - A teacher's ability to adjust learning environments was deemed proficient following the use of the T2I2 professional development materials.	**Assessment of Student Learning;** Action Research; Adapting Instruction; Data Analysis; Formative Evaluation Techniques; Initial Student Evaluation	Entry 1.4: Written Commentary
Research Hypothesis 4: H0 - A teacher's ability to contribute to the learning community was deemed proficient following the use of the T2I2 professional development materials.	**Demonstration Lesson:** Designing Standards Based STEM; Lab and Class Management; STEM Curricula	Entry 2.3: Written Commentary
Research Hypothesis 5: H0 - A teacher's ability to increase self-assessment was deemed proficient following the use of the T2I2 professional development materials.	**Documented Accomplishments:** Professional Organizations; School and Community; Student Organizations	Entry 4.1: Description and Analysis

Additional information and insight into the teachers' impressions and views about the project was gathered through interviews with the participating teachers. Teachers were emailed to schedule a brief phone interview. Interviews were conducted with select pilot teachers – both teachers who had completed all Learning Objects and units, and those who had not. While not all teachers had joined the project with the intention of becoming Nationally Board Certified, all teachers interviewed reported clear alignment of the learning objectives with NBPT requirements and found this to be an attractive characteristic of the project. Another positive aspect of participating in the project, noted by interviewed teachers, was access to the comprehensive resources provided through the project website. Teachers reported using these resources in their classrooms throughout the year.

DATA AND ANALYSIS OF FINDINGS

Data was analyzed utilizing quantitative research methods. The two years of pilot data was collected from the assessment of the teacher artifacts and analyzed as a test of hypothetical value conducted using the non-parametric Wilcoxon-signed-ranks Test. The five research hypotheses were tested to determine the teachers' abilities to monitor, manage, and adjust learning environments; contribute to learning communities; and increase self-assessment. The specified parameter for this study was a median ≥ 3 with 3 indicating a proficiency level as described and determined by NBPTS. The results of the data analysis for each of the five research questions are displayed in Table 2.

The Wilcoxon-signed-ranks Test was compared to the associated critical value based on the sample size of the participants. The participant data for the sample size was less than 50, denoting that no normal approximation with the continuity correction was necessary and the reported p-value is exact. The critical alpha value was set at 0.05 for this investigation (Noymer, 2008). The calculated p-values for the tests were determined to be larger than 0.05. The number of instances vary dependent on the number of constructs within each outcome variable.

All five research hypotheses were directional hypotheses described by the notation H1: $\Theta \geq 3$. Analysis of the pilot data resulted in the researchers failing to reject each positive directional hypothesis and suggests that participation in the T2I2 professional development sequence supports the educator's ability to monitor, manage, and adjust the learning environment; contribute to the learning community; and increase the teacher's self-assessment.

Although outside of the investigational hypotheses, teacher use and access data was also collected and analyzed as formative assessment and used for refinement of the Learning Objects within the four units. Teacher user data, seen in Table 3, included assessment scores and teacher trials. Data were collected using analytics features of the T2I2 professional development system online architecture. End-of-unit quizzes were offered as teacher participant "self-checks" to identify areas of developing competency. Each

TABLE 2: Research hypothesis examination using the Wilcoxon-signed-rank test

Research Hypothesis	*n = scoring instance possible*	*n for test*	*Median Est.*	*Wilcoxon Stat.*	*p-value*	*Method*
RH1	33	18	3.5	126	0.9476	Normal Approximation
RH2	33	24	3	88	0.9444	Normal Approximation
RH3	39	32	3	279	0.2377	Normal Approximation
RH4	37	26	3	67.5	0.9982	Normal Approximation
RH5	33	21	3	77	0.8684	Normal Approximation

TABLE 3: T2I2 professional development system teacher user data

Teacher User Data		
Units	*Mean Quiz Scores*	*Average Number of Attempts*
Assesment of Student Learning	94.50	4.50
Demonstration Lesson	100.00	3.83
Fostering Teamwork	98.46	3.15
Documented Accomplishments	97.78	3.22

quiz could be taken as many times as the teacher participant desired.

Teacher access data focused on total unit view, average unique unit views per day, and average time spent on the unit. Teacher access data were also collected using analytics features of the T2I2 professional development system online architecture. This enabled the materials development team to supplementally identify potential problem areas or specific information that was presented in a complex or inefficient fashion, warranting recurrent access or elevated duration. This data for the pilot is seen in Table 4.

The summer following the second pilot study was spent revising many aspects of the curriculum, from the number of pilot teachers to the content of the Learning Objects. Concentrated efforts modified Learning Objects within two of the four units: Assessment of Student Learning and Documented Accomplishments. These two units were the basis of the Field Study that was conducted during the 2015-2016 academic year.

Implications

Data analysis indicates that the sample population of teachers who completed T2I2 professional development was supported in their ability to manage, monitor, and adjust learning environments. The pilot group also increased its ability for self-assessment and its contributions to the learning community. The anticipated end product of this initiative is an evidence-informed system that broadens TDE teachers' instructional abilities.

Framing the coursework following coherent and national standards-based topics purposefully produced units and Learning Objects appropriate for the broader STEM in-service teacher population. Mean quiz scores greater than 94% suggest teacher competency following the completion of the Learning Objects. Total unit views ranging from 200 to 1000 demonstrate the frequency of use and entry into the system, suggesting teacher diligence in attending to the completion of this professional development.

From this study, the research team has evidence that job-embedded and flexible professional development supports the needs of in-service teachers in TDE education, and may meet the needs of teachers in other STEM disciplines. Teachers within the sample demonstrated that asynchronous learning promoted self-reflection resulting in more robust analysis of their practice.

The development of the T2I2 platform provided a venue for easy delivery of professional development content reinforced through networking and collaboration. Digital tools and platforms, like the one developed for this project, allowed for continuous customization, real-time access, and delivery to select and targeted populations (Zepeda, 2015). Teachers' classroom and professional practices were reinforced by leveraging the granular and repositionable teacher learning cyber infrastructure.

The first pilot year of the T2I2 project yielded changes and improvements for the subsequent pilot year. The various data collected show connections between the implementation of T2I2 and positive teacher classroom practices, though the low number of teacher participants does not allow results to be generalized to wider populations.

TABLE 4: T2I2 professional development system teacher access data

Teacher User Data			
Units	*Total Unit Views*	*Average Unique Unit Views per Day*	*Average Time Spent on Unit (seconds)*
Assesment of Student Learning	1001	3.65	203.4
Demonstration Lesson	395	1.59	170.2
Fostering Teamwork	376	2.00	359.4
Documented Accomplishments	205	0.95	176.2

CONCLUSIONS

Based upon this study, the authors recommend further development of this flexible professional development platform to not only address the busy schedules of in-service TDE teachers, but also to provide professional learning experiences for in-service teachers in related STEM disciplines. There are stark similarities to professional learning needs between technology and science education. Science educators face comparable pedagogical challenges and could benefit from similar professional development opportunities (Bybee, 2001). Given these similarities, this model and infrastructure provides a venue and platform that could serve as a tool for STEM educators to interact with each other, focusing on topics with common objectives. This would result in a more holistic educational experience for students, clearly following the course set by the Next Generation Science Standards.

The T2I2 platform and units created a robust network of TDE teachers. The next step for this networking may bring participating teachers' students together for cross-state collaboration, offering another opportunity to implement key educational outcomes developed within the Learning Objects.

The authors recommend continued teacher needs' assessments to identify additional topics for inclusion within the T2I2 units and Learning Objects. TDE educators come to the field with a variety of prior experiences that shape their learning needs pertaining to content and practice. The authors also recognize this diversity and suggest tailoring future T2I2 units and Learning Objects to meet these varied needs.

The current study focused on the TDE teachers' acquisition of the learning inherent within the T2I2 curriculum, considering in-progress data collection gauging: (a) how teachers use knowledge of their students to design assessments; (b) how assessment relates to course learning goals; (c) how problem-solving can be incorporated into assessment design; (d) how instructional development further fosters teamwork of students while establishing a safe and encouraging learning environment; and (e) and participation in professional activities and individual accomplishment. Further study could advance the teachers' implementation of acquired learning.

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Computer Science and Technology and Engineering Education: A Content Analysis of Standards and Curricular Resources

By Tyler S. Love and Greg J. Strimel

ABSTRACT

Recently there has been overwhelming political and financial support to include computer science (CS) in K-12 school curricula across the United States. With such strong support for CS it has been questioned where the subject would be best situated in already crowded K-12 curricula. Some have proposed integrating it within secondary level technology and engineering (T&E) courses (Ernst & Clark, 2007, 2009; Wright, Rich, & Leatham, 2012) or using CS courses in place of T&E education classes (Maryland State Department of Education [MSDE], 2016). To better inform decisions regarding CS in T&E education, this study used a multiple comparative case study (Yin, 2014) to analyze the alignment of subconcepts from the K-12 CS Framework with benchmarks from the International Technology and Engineering Educators Association's (ITEEA) Standards for Technological Literacy (STL). Additionally, a content analysis was conducted to examine curricular resources that claimed to teach CS concepts while addressing components of the STL's designed world. The purpose of the study was to investigate similarities and differences among both the CS and T&E standards and to identify curricular resources that successfully addressed multiple STL while integrating CS concepts. The findings revealed that there was limited alignment between the computational thinking and programming-focused CS framework and the broader engineering design and technology systems-focused STL. However, some curricular resources successfully used CS concepts to address many standards from the designed world section of the STL. From these findings, implications and recommendations for integrating CS within T&E education were provided.

Keywords: technology and engineering education, computer science, standards

INTRODUCTION AND BACKGROUND

Including computer science (CS) education within K-12 curricula in the United States has received increased support in recent years. This may be in response to the rapidly growing demand for preparing individuals to address critical issues such as cyber security attacks. Such support for CS has been demonstrated in various aspects. In 2016, President Obama introduced his "Computer Science for All" initiative. The goal of this new initiative was to empower all students from kindergarten through high school to learn CS concepts and be equipped with the computational thinking skills deemed necessary for success in a technological society. To achieve this goal, President Obama called for $4 billion in funding for states and $100 million directly for school districts to train teachers and expand access to CS (The White House, 2016). Also in 2016, the National Science Foundation (NSF) made $120 million available over five years and the Corporation for National and Community Service (CNCS) committed up to $17 million over a three-year period to support CS education (The White House, 2016). Furthermore, the Computer Science Education Coalition, composed of 43 members ranging from industry (i.e., Google, Amazon, Microsoft, and IBM) to nongovernment organizations (i.e., Computing Research Association and the Association for Computing Machinery), has actively encouraged Congress to invest millions of dollars in K-12 CS education (Computer Science Education Coalition, 2016). Since 2015, 20 state policies supporting CS education have successfully passed legislation and eight more state policies are pending as of 2016 (Code.org, 2016). As a result of this increased attention and support, programs, such as the Hour of Code, which is a series of one-hour online tutorials to introduce students to coding, have continued to develop. More than 200,000 educators worldwide now implement the Hour of Code program in their schools (Code.org, 2016).

Graduation Requirements

In response to the growing emphasis on the critical need for more student exposure to CS and the increased national support for K-12 CS education, various states that have allowed CS coursework to be used to fulfill high school graduation requirements. The number of states allowing CS to fulfill high school graduation requirements has increased from 12 in 2012 to 33 in 2016 (Code.org, 2016). The majority (20) of these states count CS courses to toward mathematics graduation credit requirements, whereas fewer states count CS courses as graduation credits in mathematics or science (10), science (1), mathematics or foreign language (1), and technology and engineering (T&E) (1) (Code.org, 2016). In addition to allowing CS coursework to fulfill high school graduation requirements, some states (Arkansas, Texas, and West Virginia) have passed legislation to require schools at various grade levels to offer at least one computer science course (Iowa and New Jersey are currently awaiting final signatures requiring all secondary schools to offer CS) and seven states have established CS standards (Code.org, 2016). Moreover, in 2016 Chicago Public Schools approved a policy requiring all high school students to complete CS coursework as one of their core graduation requirements (Chicago Public Schools, 2016).

Teacher Preparation

However, requisite to requiring CS course offerings and enabling CS courses to fulfill graduation requirements is finding qualified educators who are prepared to teach these courses. The New Hampshire Department of Education noted that the biggest challenge for their *CS for all New Hampshire* initiative has been recruiting and training teachers, because finding enough individuals to meet the demands for CS-related jobs and finding enough qualified individuals who will teach CS go hand in hand (Duffort, 2016). Wright, Rich, and Leatham (2012) also raised the concern for finding quality CS teachers by highlighting that there was a CS certification exam for high school teachers in some states but no general requirements for CS teacher certification in most states. The Computer Science Teachers Association (CSTA) (2013) also reported that two states require a certification or license to teach any CS courses, seven states require training to teach Advanced Placement (AP) CS courses, and 13 states offer a certification, licensure, or supplemental endorsement, but they do not require teachers to obtain these credentials to teach CS courses. Further complicating matters, the CSTA reported that CS courses in which the certifications or endorsements were offered, were often delivered via a variety of high school departments, which included CS, business, mathematics, T&E education, fine and practical arts, library science departments, and career and technical education (CTE) departments. In recognition of this, the K-12 CS Framework (2016) acknowledged the need to train educators for teaching CS and provided guidelines for professional development. The Framework suggested developing a CS teacher licensure exam for endorsement, instituting CS as a CTE pathway, or requiring CS as part of existing T&E education pathways.

Defining CS and T&E Education

T&E education (formerly technology education) has long battled the stigma of being mistaken for instructional or educational technology (Dugger & Naik, 2001; ITEEA, 2016). The K-12 CS Framework defined CS as “the study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications, and their impact on society” (Tucker et. al, 2006, p. 2), whereas T&E education:

> Includes major areas that have characteristics that define it and distinguish it from others. Some examples of major areas that could be included in a taxonomy of the designed world are medical technologies, agricultural and related biotechnologies, energy and power technologies, information and communication technologies, transportation technologies, manufacturing technologies, and construction technologies…they represent the dynamic and the broad spectrum of technology that permeates our world today. (Dugger & Naik, 2001, p. 31)

Regardless of the differences in the definitions, many people continue to confuse CS with T&E education. This was evident in Khoury's (2007) survey of 45 states, which found that many individuals did not have a clear definition or understanding of CS and confused it with technology education or industrial technology.

CS within T&E Education

Despite this confusion, some T&E education researchers have advocated for the inclusion of CS within T&E education. Clark and Ernst (2008) believed that incorporating CS was "a truly new way of seeing what technology education can do to support both state and federal initiatives in education" (p. 26), and that it would "allow for the integration of science and technological literacy to occur through the study of data visualization and the development of both virtual and physical models" (p. 21). Additionally, they found that CS could assist with drop-out rates, 21st-century skills (Clark & Ernst, 2008), and the development of scientific and technical visualization skills related to communications, medical, biotechnology, transportation, and energy and power technologies (Ernst & Clark, 2007, 2009).

Wright et al. (2012) declared that CS, specifically programming literacy, should be incorporated as part of T&E education and the STL "much like construction technology, manufacturing technology, medical technology, and so forth are included" (p. 6) because they "may increase critical-thinking and problem solving abilities" (p. 8). Wright et al. (2012) defined programming literacy as "being able to effectively, efficiently, and safely interact, use, and manipulate communication technologies" (p. 5), and highlighted that because technology is constantly evolving, new and effective technological areas, such as CS, should be integrated within T&E education. They believed that programming literacy had a significant relationship with many fields of technology and that the social, political, economic, and environmental impact has an affect on the world. Given the definition and applications of computer programming they suggested similar to Ernst and Clark (2007, 2009) that CS not be viewed as a replacement for T&E education, rather that it be considered and incorporated as one of the designed world components, specifically within information and communications technologies.

Policy Changes

The misconception that CS is the same as T&E education and the ambiguity of how to best integrate the two has had an effect on policy changes and instructional decisions made in some states. Specifically the state of Maryland is the only state to count CS toward the T&E education graduation requirement (Code.org, 2016), and there have been changes made by the Maryland State Department of Education (MSDE) that have affected what constitutes as T&E education coursework. In January of 2016, MSDE revised their technology education standards, which were based on the International Technology and Engineering Educators Association's (ITEEA) Standards for Technological Literacy (STL), to include CS with the addition of Standard 5, "Students will be able to apply computational thinking skills and computer science applications as tools to develop solutions to engineering problems" (p. 20). In addition to this new standard, MSDE also added a CS pathway to the list of preapproved courses that satisfied the T&E graduation requirement, giving school systems the option to offer CS classes in lieu of T&E education courses (MSDE, 2016, p. 6). However, Love, Dunn, and Tomlinson (2016) indicated that the CS classes that were preapproved by MSDE fell short of covering all core technologies (biotechnology, electrical, electronics, fluid, materials, mechanical, optical, structural, and thermal) and components of the designed world (medical/agricultural/biotechnology, energy and power, information and communication, transportation, and manufacturing and construction technologies) as mandated by the Code of Maryland (COMAR) 13A.04.01.01 (MSDE, 2016).

RESEARCH QUESTIONS

The preapproval to use CS courses in lieu of T&E education classes can be of concern for T&E education programs facing a critical teacher shortage (Love, Love, Love, 2016).

Furthermore, it can misrepresent T&E education as solely the use of computers, electronic devices, programming, and coding. As specified in COMAR (MSDE, 2016) and clarified by Dugger and Naik (2001), T&E education is focused on the broader scope of technology – providing technological literacy for all students while introducing them to the various core technologies, designed world components, and immersing them in the engineering design process. The different definitions of CS and T&E, yet the sometimes interchangeable use of CS for T&E courses led the researchers to develop the following questions to examine the relationship between the two content areas:

> *1. To what extent does each of the K-12 CS Framework subconcepts for grades 9-12 align with the STL benchmarks for grades 9-12?*
>
> *2. To what extent do select curricular resources integrate CS concepts in alignment with the designed world components of the STL?*

METHODOLOGY

To provide rigorous qualitative data examining the alignment of the standards, a multiple comparative case study (Yin, 2014) was conducted. A multiple comparative case study analyzes for similarities, differences, and patterns across two or more cases that share a common focus or goal. The researchers examined the high school K-12 CS Framework subconcepts as well as the high school benchmarks from the STL. The contents from each field were analyzed separately, and then those analyses were compared to reveal emerging similarities or differences. The researchers who performed the analyses had expertise in T&E teacher preparation and experience with writing T&E education curriculum. The researchers started by creating a chart with each of the K-12 CS Framework subconcept statements for grades 9-12; they then compared each subconcept with what was deemed to be the closest aligned STL benchmark(s) for grades 9-12. From these analyses emerged themes that reflected the comparative content from both sets of standards (Table 1). Each researcher analyzed the standards separately and then arbitrated the differences until a consensus was reached. To ensure accuracy of the interpretation of the CS framework, one graduate student with expertise in CS and one with expertise in electrical engineering reviewed the analysis and provided feedback that helped corroborate the results.

The researchers also analyzed a number of curricular resources they found throughout their research that claimed to teach CS and T&E education concepts. A content analysis was conducted to examine the literature and research presented on these curricular resources to determine what STL designed world components they covered. The result was a list of resources that demonstrated the use of CS as a tool to teach these designed world components. To corroborate the accuracy of the curricular resource analysis, the researchers had the author(s) of each resource review the description presented in Table 2 and incorporated their feedback.

FINDINGS

To answer the first research question, “To what extent does each of the K-12 CS Framework subconcepts for grades 9-12 align with the STL benchmarks for grades 9-12?” a multiple comparative case study analysis was conducted to compare the subconcept statements of the K-12 CS Framework to the closest aligned grade 9-12 benchmark(s) from the STL. Findings are presented in the analysis column of Table 1 on page 80.

TABLE 1: Comparative Content Analysis of the K-12 CS Framework and the STL

Comparative Content	*CS Subconcepts and STL Benchmarks*	*Analysis*
Interactions Among Technologies	CS: Devices STL: 3H - Relationships Among Technologies and the Connections Between Technology and Other Field	The CS framework was specific to computing devices integrated with other scientific, technological, or social systems, whereas the STL asserted that any type of technological innovation (not just those involving computers) could be applied within and among various technologies or across other fields.
Transfer of Information	CS: Hardware and Software STL: 17M - Information and Communication Technologies	Both emphasize the systems model, but the CS Framework is focused on software and hardware interactions for controlling and processing information while the STL were focused on the transfer of information and applications for the communication of many technologies (not only computer software and hardware).
Solving Problems	CS: Troubleshooting CS: Algorithms STL: 8H - Attributes of Design STL: 2Y – Core Concepts of Technology	Both are focused on using the engineering design process (EDP), but while the STL focused on using all phases of the EDP to create physical models and prototypes, the CS Framework only focused on a few of the EDP phases to produce prototypes of computational artifacts, such as programs, simulations, visualizations, and apps.
The Use of Computational Tools	CS: Program Development CS: Data and Analysis CS: Visualization and Transformation STL: 12P - Use and Maintain Technological Products and Systems	The CS Framework was focused on using computational tools and programs to perform calculations, process data, transform data, and transfer data, whereas the STL is focused on utilizing computers and calculation devices as technological tools to communicate data and inform designs to problems.
Networks	CS: Network Communication and Organization STL: 17O - Information and Communication Technologies	The CS Framework was focused on a more in-depth study of the topology or structure of computer networking systems while the STL broadly discussed how communication systems transfer information, not including the topography of networking systems.
Collection of Data	CS: Collection STL: 12P - Use and Maintain Technological Products and Systems	The CS Framework was concerned with computer and network-automated tools used to collect numerical data and the security of those data collection systems. The STL did not address data collection methods or data security, rather it focused on collection of data to inform engineering design practices, which was not limited to computers and automated tools.

Note. CS = K-12 Computer Science Framework (2016) subconcept; STL = Standards for Technological Literacy benchmark (ITEA/ITEEA, 2000/2002/2007).

Comparative Content	***CS Subconcepts and STL Benchmarks***	***Analysis***
Storage and Retrieval of Data	CS: Storage STL: 17O - Information and Communication Technologies	The CS Framework emphasized the specific processes for organizing data in relation to storing, accessing, and archiving information using computer and network systems whereas the STL focused on the broader view of how information is transferred through a communication system.
Representation of Data	CS: Visualization and Transformation STL: 17P - Information and Communication Technologies STL: 3H - Relationships Among Technologies and the Connections Between Technology and Other Fields	The CS Framework was focused specifically on the application of mathematical operations to transform and analyze data to be represented by computer software and programming while the STL emphasized various technologies (electronic and non-electronic) can be used to represent data and apply concepts from various fields (not just mathematical operations) to foster innovation.
Modeling	CS: Inference and Models STL: 11P - Apply the Design Process	CS Framework was focused on using computers to create data models for developing inferences and predictions to test and validate computer model data. The STL was focused on creating and evaluating various types of models throughout all phases of the engineering design process to not only predict but also evaluate design solutions not limited to computer generated or mathematical models.
Mathematical Applications	CS: Algorithms CS: Visualization and Transformation STL: 3J - Relationships Among Technologies and the Connections Between Technology and Other Fields	The CS Framework focused specifically on using computational systems and programs to perform calculations while the STL emphasized the application of both mathematical and scientific concepts to aid in engineering design decisions and advance various technologies (not limited to programming, software, and computers).
Structuring of Data	CS: Variables STL: 17Q - Information and Communication Technologies	The CS Framework emphasized programming knowledge and data structures as a means for improving programming and program efficiency, whereas the STL focused on visual, auditory, and tactile methods to effectively communicate data.
Determining Tradeoffs	CS: Control STL: 4I - The Cultural, Social, Economic, and Political Effects of Technology	The CS Framework focused on considering the tradeoffs specifically related to choice of programming language for control structures, however the STL focused on the broader global, environmental, cultural, safety, societal, and economical tradeoffs associated with various technologies beyond programming.

Note. CS = K-12 Computer Science Framework (2016) subconcept; STL = Standards for Technological Literacy benchmark (ITEA/ITEEA, 2000/2002/2007).

TABLE 1: Comparative Content Analysis of the K-12 CS Framework and the STL (Continued)

Comparative Content	*CS Subconcepts and STL Benchmarks*	*Analysis*
Systems Approach	CS: Modularity STL: 2Y – The Core Concepts of Technology	The CS Framework focused on systems design using programming language for software applications, module relationships, and program management while the STL focused on systems thinking related to natural and manmade control systems related to many technologies, beyond software applications and programming.
Societal Access to Technology	CS: Culture STL: 4K - The Cultural, Social, Economic, and Political Effects of Technology	The CS Framework focused on the design of computing technologies and artifacts to provide equitable societal access to such technologies while the STL focused on the broader cultural, social, economic, and political effects that various forms of technology have on society.
Greater Societal Impact	CS: Cybersecurity CS: Social Interactions STL: 4I - The Cultural, Social, Economic, and Political Effects of Technology STL: 4K - The Cultural, Social, Economic, and Political Effects of Technology STL: 17N - Information and Communication Technologies	The CS Framework emphasized that computing and network security measures have helped to connect people from different cultures and career fields while considering tradeoffs between accessibility and security. The STL focused on the various uses of many types of communication systems and the decision making process to consider both positive and negative global, environmental, cultural, safety, societal, and economical trade-offs of technologies.
Safety and Ethics	CS: Safety, Law, and Ethics STL: 9L - Engineering Design	The CS Framework focused on legal issues and tradeoffs related to computing, specifically Internet usage, whereas the STL focused on a broader scope of safety and ethical issues that affect society such as safety, reliability, economic considerations, quality control, environmental concerns, manufacturability, maintenance and repair, and ergonomics.

Note. CS = K-12 Computer Science Framework (2016) subconcept; STL = Standards for Technological Literacy benchmark (ITEA/ITEEA, 2000/2002/2007).

To answer the second research question, “To what extent do select curricular resources integrate CS concepts in alignment with the designed world components of the STL?” the researchers conducted a content analysis of courses they discovered during their research that claimed to teach both T&E and CS concepts. The curricular resources presented in Table 2 were ones that the analysis found to demonstrate the best use of CS as a tool for teaching various designed world components (Table 2).

TABLE 2: Curricular Resources that Addressed Components of the STL Designed World Using CS

Curricular Resource	***Description***	***STL Designed World Components***
Precision Farming	The FarmBot is an example of an open-source CNC system operating from Arduino and Raspberry Pi coding that makes precision farming possible (Lentz, 2016). Teachers can work with students to create a track structure (structural and manufacturing technologies) and program (information and communication systems) for more efficient crop growth (agricultural and biotechnology).	A, C, E, I, Ma
Microcomputers and Sensors (e.g., Raspberry Pi)	Love, Tomlinson, and Dunn (2016) provided a wealth of instructional resources for utilizing programming to control various sensors and solve authentic engineering design challenges such as a smart house.	C, E, I, Ma, T
Scientific and Technical Visualization I & II	These standards-based curricula by ITEEA (p. 7) are focused on using complex graphic and visualization tools such as graphics and animation software to illustrate, explain, and present technical, mathematical, and scientific concepts. Ernst and Clark (2007) demonstrated learning gains related to the various designed world components as a result of these curricula.	A, C, I, Ma, Me, T
Game Art and Design	This standards-based curricula by ITEEA (p.7) teaches students about the basics of game theory and strategic thinking to create a working prototype of a board game. In this curricula, students learn basic knowledge and skills that relate to fundamental programming concepts associated with the industry. Lesson topics such as probability and Nash Equilibrium have proven to be important in many fields of learning including biology, computer science, politics, agriculture, and economics. Ernst and Clark (2007) found this curriculum to be very engaging while addressing many technology and science standards.	I
Cyber Security	This unit from ITEEA's Advanced Technological Applications (ATA) curriculum was developed in collaboration with the U.S. Naval Academy and addresses an array of science, technology, engineering, and mathematics (STEM) standards. Current research efforts (NSF, 2015) are examining the learning of cyber security through representational fluency, which is a powerful tool to teach complex concepts in science and mathematics.	I
Advanced Manufacturing	Loveland (2012) demonstrated how learning basic G & M code promotes higher order technology and mathematics thinking. Students must apply advanced math and technological problem solving skills to operate computer numerical control (CNC) lathes, milling machines, and routers. Even if schools do not have these advanced manufacturing machines, students can still simulate the manufacturing process through Computer Aided Manufacturing (CAM) software.	I, Ma
Robotics	There are various robotics curricula available that can be beneficial to student learning, for example, as Berenguel et al. (2015) demonstrated. Those that go beyond kits, and require students to design and construct their own robotic systems apply many STEM skills. Additionally, they integrate programming with engineering design to solve problems related to many of the designed world components.	C, E, I, Ma, T

Note. STL = Standards for Technological Literacy benchmark (ITEA/ITEEA, 2000/2002/2007); A = agricultural and biotechnology; C = construction; E = energy and power; I = information and communication systems; Ma = manufacturing; Me = medical; T = transportation

DISCUSSION

Even though the content analyses revealed similarities and differences among subconcepts and benchmarks, and the standards addressed by certain curricular resources, a few limitations should be acknowledged. The benchmarks in Table 1 were those the researchers selected as the best aligned based on their analysis of the STL. It is also important to note that the researchers did not have access to information about all CS curricula, for example, the recently released Project Lead the Way (PLTW) CS pathway. The analysis presented in Table 2 did not examine the content of specific lessons and units within the curricula, only descriptions and previous research findings related to those curricula were analyzed.

From the comparative content analysis presented in Table 1, it is clear that there were differences in how technology was viewed in both the K-12 CS Framework and the STL. The CS Framework was more narrow in scope regarding technology, focusing primarily on an in-depth study of computers, electronic devices, programming, and computational thinking; in comparison, the STL had used a broader perspective of the various technologies across all industries that affect the world (medical, agricultural and biotechnology, energy and power, information and communication, transportation, manufacturing, and construction technologies). Although the STL acknowledged that electronic technologies such as computers are important, they also indicated it is not the only technology that students must understand how to analyze, design, and troubleshoot. This difference in technological content presented a challenge for analyzing two of the CS subconcepts (cyber security and data collection) that did not fully align with a STL benchmark. Cyber security was included in the Greater Societal Impact category because it had a similar focus. Also, as mentioned in the analysis column, there was no specific STL benchmark that fully aligned with the CS subconcept of data collection. This benchmark issue highlighted that both the CS Framework and the STL had different strengths for different purposes, and they were not fully aligned between each subconcept and benchmark.

Regarding the design processes, the CS Framework emphasized the importance of the design process and troubleshooting, but it did not provide the specific procedures of engineering design, which are core components of T&E education. However, according to the Framework, researching, evaluating, troubleshooting, and implementing potential solutions were discussed. Examples that the framework provided of complex problem solving strategies included: computer-focused issues, such as resolving connectivity problems, adjusting system configurations and settings, ensuring hardware and software compatibility, transferring data, and identifying the effects of lingering bugs. In contrast, the STL focused more on the practices of design processes and engineering design, such as defining the problem, brainstorming, researching and idea generation, criteria identification and constraint specification, possibility exploration, approach selection, design proposal developments, model or prototype, making and testing, and the evaluation of design using specifications, redefinition, creation, communicating processes and results. The STL also emphasized the broader applications of engineering design to develop solutions and functional physical prototypes in order to answer technological problems beyond specific electronic issues.

Furthermore, the CS Framework and STL may differ in their alignment to other content areas. Only in the *Devices* subconcept statement did the CS Framework mention a connection to science practices, citing integration of computing devices with biological systems. However, mathematics connections such as algorithms, variables, data visualization and transformation, and computational modeling were embedded throughout the framework. In contrast, the STL provided examples of the relationships between mathematics, science, and other content areas to inform technological innovation. For example, Standard 5 described specific scientific examples regarding the effects of technologies on the environment, and Standard 16 cited explicit connections between technologies, energy, and power concepts, such as conservation of energy and thermodynamics. The STL also advocated for T&E educators to integrate content from other areas in order to provide a more holistic experience to learning science, technology, engineering, and mathematics (STEM) (p. 6). The findings described above may be the reason that most states classified CS classes as a mathematics requirement rather than a T&E education graduation requirement.

The second research question revealed that though the CS Framework and the STL may have had different foci, some curricular resources demonstrated the possibility to use CS as a teaching tool for components of the STL designed world as suggested in the literature (Ernst & Clark, 2007, 2009; Wright, Rich, & Leatham, 2012). Using this approach would align educators with MSDE technology education Standard 5 which dealt with the application of computational thinking skills and CS as tools to develop solutions to engineering problems. Each resource in Table 2 covered multiple designed world standards. This content analysis demonstrated that when planned properly, CS concepts can be integrated in T&E education courses as a tool for teaching about various components of the designed world and creating engineering design solutions while also developing students' computational thinking skills. These findings provide a hopeful outlook for integrating CS and T&E education, while still promoting technological and engineering literacy for all students.

CONCLUSIONS

From the analyses it became evident that there were differences between the K-12 CS Framework and STL, specifically the narrow versus broad views of technology. Despite these differences the content analysis revealed there are successful curricular resources that have utilized CS as a tool to teach multiple components of the designed world portion of the STL and CS concepts. Given these examples, T&E educators should view CS as a tool to engage students and teach T&E content and practices while integrating CS concepts in an authentic engineering context. Integrating CS in T&E does not come without reservations though. As indicated in the review of literature, some policy makers and administrators may confuse CS with T&E education, despite differences among the definitions, the subconcepts, and the benchmarks. It is critical that T&E educators communicate these differences and demonstrate ways that T&E uses CS to solve engineering problems beyond simply electronics, information, and communication technologies. Applications of CS in an authentic engineering design context can highlight both the similarities and differences between CS and T&E education, and may help in maintaining a more comprehensive technological and engineering focus that can introduce students to numerous career and college options, beyond those focused solely on computers and electronics.

Implications and Recommendations

A number of implications and recommendations for researchers and practitioners can be drawn from this study. It must be noted that this research only examined the standards and curricular resources from a surface level; therefore, to better understand how specific CS courses can be implemented nationwide (e.g., Advanced Placement CS, PLTW CS pathway) further research is needed to examine to what extent the objectives, units, lessons, and other instructional resources align with the STL. Analyzing courses at this level may provide a deeper understanding of how CS is being applied to meet the STL and help all students achieve technological and engineering literacy. Moreover, because this study determined that CS can be used as a tool to teach T&E concepts, further research is warranted to examine how CS can be integrated with the designed world components of the STL. Wright et al. (2012) suggested that CS could be included within Standard 17 because programming is a form of communication technology. However, as a result of the findings, it is recommended that T&E teachers work to develop rigorous STEM curricula in collaboration with CS, science, and mathematics educators to serve as a bridge between CS and STEM education. In addition, the researchers of this article recommend that programs for T&E teacher preparation strive to integrate CS concepts within engineering design coursework and link CS applications to the learning of communications and electronics in T&E courses.

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